COST STUDIES OF MULTIPURPOSE LARGE LAUNCH VEHICLES

VOLUME VI

COST IMPLICATIONS OF VEHICLE SIZE, TECHNOLOGY CONFIGURATION AND PROGRAM OPTIONS

FINAL REPORT

SEPTEMBER 15, 1969

NASA DOCUMENT NO.

CR-73333

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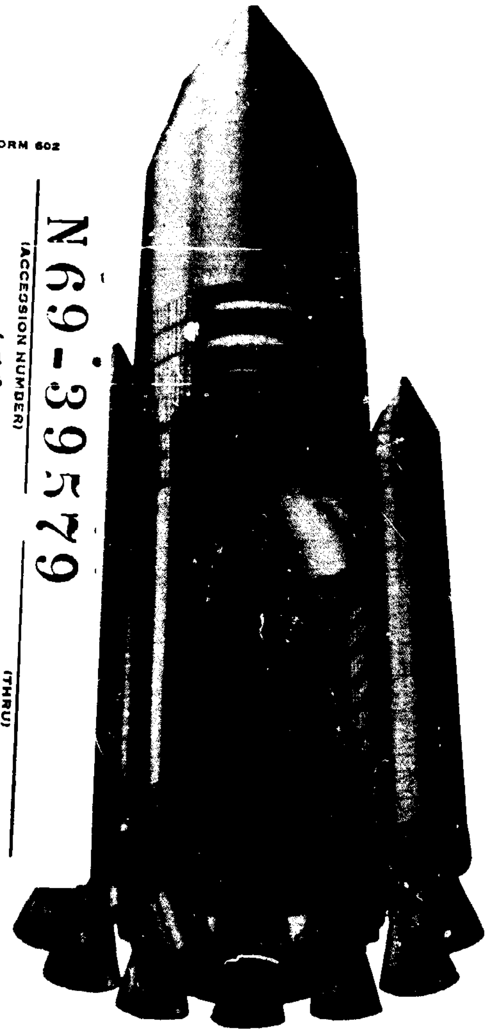

PREPARED UNDER CONTRACT
NAS 2-5056

BY THE BOEING COMPANY
AEROSPACE GROUP
SOUTHEAST DIVISION

(BOEING DOCUMENT NO.
D5-15469-6)

FINAL REPORT
FOR
COST STUDIES OF MULTIPURPOSE LARGE LAUNCH VEHICLES

VOLUME VI
COST IMPLICATIONS OF VEHICLE SIZE, TECHNOLOGY, CONFIGURATION, AND PROGRAM OPTIONS

PREPARED UNDER CONTRACT NAS2-5056
FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF ADVANCE RESEARCH AND TECHNOLOGY
MISSION ANALYSIS DIVISION
SEPTEMBER 15, 1969

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ABSTRACT

Nine volumes including this volume present the final report documentation outlining the accomplishments for the "Cost Studies of the Multipurpose Large Launch Vehicles" (MLLV). NASA/OART Contract NAS2-5056. This volume presents an assessment of and application for the overall study results to show cost implications of vehicle size, technology, configuration and program options.

The MLLV family will consist of a single-stage-to-orbit configuration plus other configurations consisting of a main stage (as used for the single-stage-to-orbit configuration) with various quantities of 260 inch diameter solid rocket motor (SRM) strap-on stages and/or injection stage modules. The main stage will employ LOX/LH_2 propellant with either a multichamber/plug or toroidal/aerospike engine system. The single-stage-to-orbit configuration will have a payload capability of approximately 500,000 pounds to a 100 nautical mile earth orbit. With the addition of the strap-on SRM stages and/or LOX/LH_2 injection stage modules this payload capability can be increased incrementally to as much as 1,850,000 pounds.

The contract consisted of four study phases. The Phase I activity was a detailed cost analysis of an Advanced Multipurpose Large Launch Vehicle (AMLLV) family as previously defined in NASA/OART Contract NAS2-4079. Costs for vehicle design, test, transportation, manufacture and launch were defined. Resource implications for the AMLLV configurations were determined to support the cost analysis.

The Phase II study activity consisted of the conceptual design and resource analysis of a smaller or half size Multipurpose Large Launch Vehicle (MLLV) family.

The Phase III activity consisted of a detailed cost analysis of the smaller Multipurpose Large Launch Vehicle configurations as defined in Phase II. Costs for vehicle design, test, transportation, manufacture and launch were determined.

The Phase IV activity (as reported in this Volume) assessed the results of the study including the implications on performance, resources and cost of vehicle size, program options, and vehicle configuration options. The study results provided data in sufficient depth to permit analysis of the cost/performance potential of the various options and/or advanced technologies.

ABSTRACT (Continued)

KEY WORDS

Advanced Multipurpose Large Launch Vehicles (AMLLV)

Half Size Multipurpose Large Launch Vehicles (MLLV)

Single-Stage-to-Orbit

Multichamber/ Plug Engine System

Toroidal/Aerospike Engine System

260 Inch Solid Propellant Rocket Motor (SRM)

Orbital Injection Stage

Contract NAS2-4079

Contract NAS2-5056

Payload to 100 NM Orbit

Cost

Resources

Zero Stage Vehicles

Parallel Stage Vehicles

Main Stage Throttling

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FOREWORD

This volume, Cost Implications of Vehicle Size, Technology, Configuration, and Program Options, is one of nine volumes documenting the results of a twelve month study program "Cost Studies of Multipurpose Large Launch Vehicles", NASA/OART Contract NAS2-5056. The objective of this study was to define cost, cost sensitivities, and cost/size sensitivities of potential future launch vehicles to aid in the guidance of current and future technology programs. The baseline vehicles utilized to make this assessment were:

1. The Advanced Multipurpose Large Launch Vehicles (AMLLV) as defined under NASA/OART Contract NAS2-4079.

2. The Multipurpose Large Launch Vehicles (MLLV) as defined under this contract and described in Volume II, "Half Size Vehicle (MLLV) Conceptual Design".

The program documentation includes this volume plus a Summary Volume, a Design Volume, a Resources Volume, Cost Volumes, an Advanced Technology Implications Volume, and Appendices Volumes. Individual designations for these volumes are as follows:

Volume I	Summary
Volume II	Half-Size Vehicle (MLLV) Conceptual Design
Volume III	Resource Implications
Volume IV	Baseline AMLLV Costs
Volume V	Baseline MLLV Costs
Volume VI	Cost Implications of Vehicle Size, Technology, Configuration, and Program Options
Volume VII	Advanced Technology Implications
Volume VIII	Flight Control and Separation, and Stress Analysis (Unclassified Appendices)
Volume IX	Propulsion Data and Trajectories (Classified Appendices)

Data on the 260 inch diameter solid propellant rocket motor were obtained from the Aerojet General Corporation. Data on the multichamber/plug propulsion system were obtained from the Pratt and Whitney Division of the United Aircraft Corporation

FORFWORD (Continued)

and the Rocketdyne Division of the North American Rockwell Corporation. Data on the toroidal/aerospike propulsion system were obtained from the Rocketdyne Division of the North American Rockwell Corporation.

These propulsion data were obtained from the propulsion contractors at no cost to the contract. The material received encompassed not only the technical data, but resources, costs, schedules and advanced technology information. This support materially aided The Boeing Company in the preparation of a complete and meaningful study and is gratefully acknowledged.

This study was administered under the direction of NASA/OART Mission Analysis Division, Ames Research Center, Moffett Field, California under the direction of the technical monitor, Mr. Edward W. Gomersall.

1.0 INTRODUCTION

This study was directed to define the economic aspects of a future launch vehicle system. This work complements the previously completed technological study, "Advanced Multipurpose Large Launch Vehicles", Contract NAS2-4079. (This study is hereinafter referred to as the reference study. The vehicle family defined by this prior study is hereinafter referred to as the baseline AMLLV family.)

The economic aspects to be defined included:

a. The non-recurring and recurring costs for implementation and operation of the baseline AMLLV family.

b. The non-recurring and recurring costs for implementation and operation of a half size (MLLV) vehicle family. (Payload capability half that of the baseline AMLLV family.)

c. Cost effectiveness of program and configuration options.

d. Cost/size implications, and performance/cost implications of advanced technology applications.

The baseline AMLLV family as defined by the referenced contracted study consisted of:

a. A single stage to orbit baseline vehicle capable of injecting one million pounds of payload into a 100 n. mi. low-earth orbit.

b. Injection stage modules which are additive to the main stage for increased payload capability and payload maneuvering.

c. Strap-on solid or liquid propellant rocket motors for main stage thrust augmentation to improve payload capability.

The design, test, manufacturing, handling and transportation, facilities and launch plans developed under the referenced contracted study were used as a basis for cost definition.

The baseline AMLLV vehicle family is depicted in Figure 1.0.0.0-1. Payload performance for this family is summarized in Figure 1.0.0.0-2.

The baseline MLLV family was that family defined by this study and shown in Volume II. The basic MLLV vehicle configuration employed the following components:

CORE VEHICLE

GROSS PAYLOAD ≈ 1.0M LBS. WITH EITHER PROPULSION SYSTEM

LIGHT WEIGHT SKIRT

T_O = 16M LBS.

T/W = 1.25

W_O = 12.8M LBS.

W_P TOTAL = 11.1M LBS.

MULTICHAMBER/PLUG

PRATT & WHITNEY HIGH PRESSURE BELL ENGINES

λ' = .94

OR

TOROIDAL AEROSPIKE

ROCKETDYNE

P_C = 2000 PSI

λ' = .946

CORE + INJECTION STAGE

GROSS PAYLOAD = 1.18 M LBS.

T/W_O = 1.18

LIGHT WEIGHT SKIRT

INJECTION STAGE

$W_{I.S.}$ = 550,000 LBS.

W_P = 450,000 LBS.

$\lambda'_{I.S.}$ = .82

THRUST = 500K LBS. (2 ENGINES)

CORE + STRAP-ON'S

GROSS PAYLOAD = 3.52 M LBS. (12 STRAP-ONS)

HEAVY WEIGHT SKIRT

W_O = 15.36 M LBS.

260" STRAP-ONS λ'_S = .90 (INCL. STAGE COMPONENTS)

NO.	W_P (M LBS.)	T_O (M LBS.)	T_O/W_O
12	45.7	108	1.63
8	30.5	72	1.49
4	15.2	36	1.18

260" MOTOR PERFORMANCE (EACH)

W_P = 3.81 M LBS.

F = 9.0 M LBS.

CORE + STRAP-ON'S + INJECTION STAGE

GROSS PAYLOAD = 3.74 M LBS.

HEAVY WEIGHT SKIRT

STRAP-ON MOTORS $\lambda'S$ = .90

NO	W_P	T	T_O/W_O
12	45.7M	108M	1.59

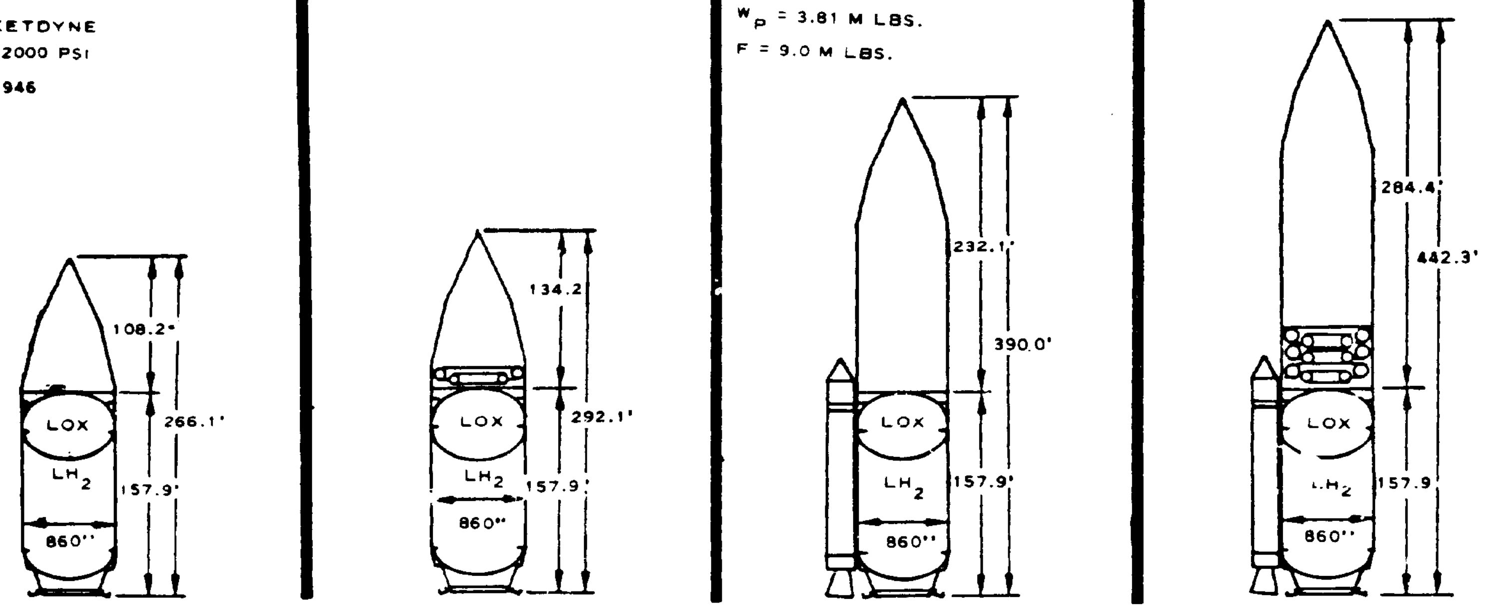
INJECTION STAGE

$W_{I.S.}$ = 1.614 M LBS.

W_P = 1.350 M LBS.

$\lambda'_{I.S.}$ = .87

T = 1.50 M LBS (6 ENGINES)



CORE VEHICLE | CORE + INJECTION STAGE | CORE + STRAP-ON'S | CORE + STRAP-ON'S + INJECTION STAGE

■ ALL PAYLOADS SHOWN FOR ρ = 5 LBS/FT^3 100 NAUTICAL MILE CIRCULAR ORBIT

FIGURE 1.0.0.0-1 ADVANCED MULTIPURPOSE LARGE LAUNCH VEHICLE BASELINE FAMILY

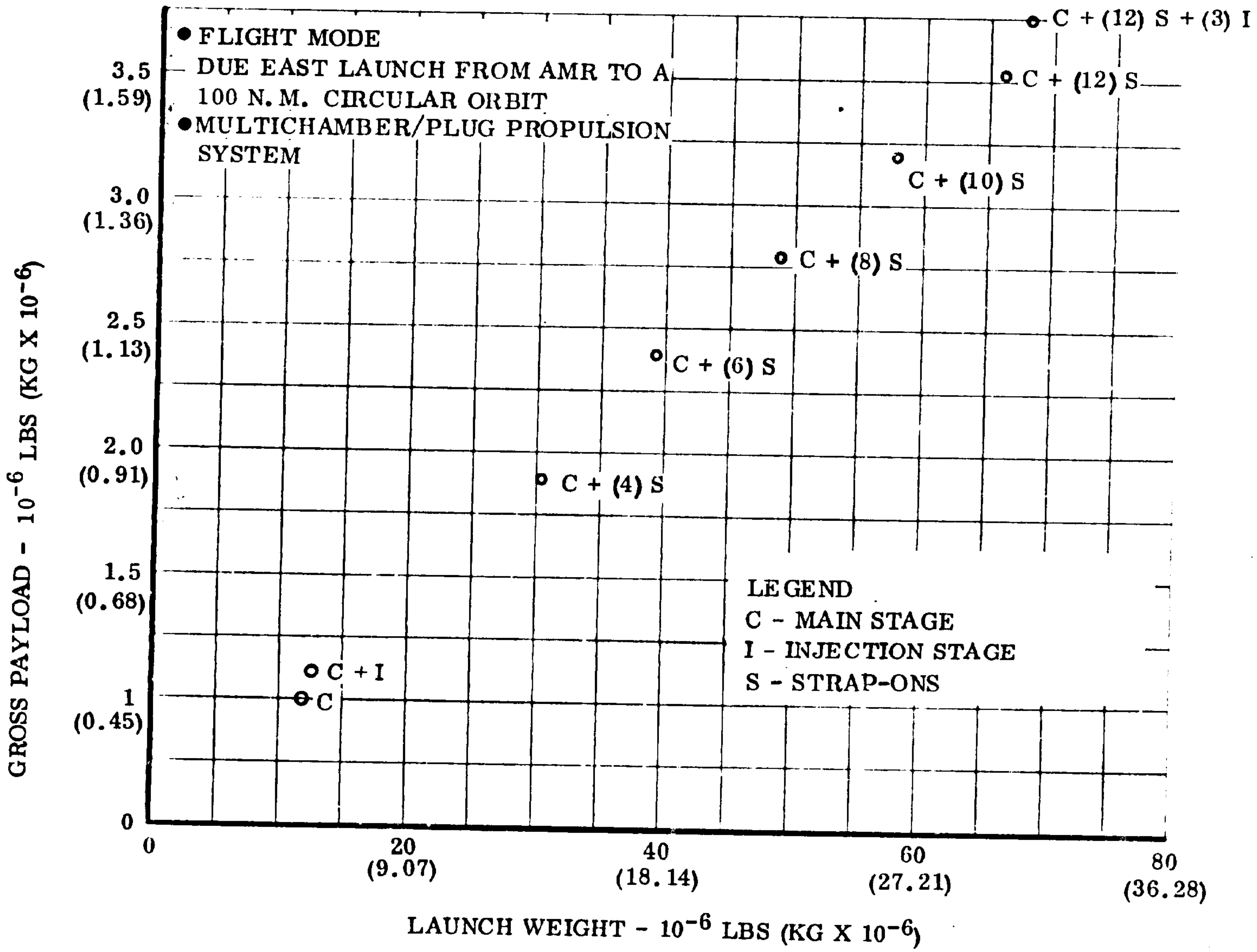


FIGURE 1.0.0.0-2 AMLLV PAYLOAD VERSUS LAUNCH WEIGHT

1.0 (Continued)

a. Main (Core) Stage - Sized to provide a single-stage-to-orbit payload of approximately 500, 000 pounds. Propellants will be liquid oxygen (LOX) and liquid hydrogen (LH_2). Two different engine systems, the multi-chamber/plug (Pratt and Whitney) and the toroidal/aerospike (Rocketdyne) were considered for the main stage.

b. Injection Stage - A modular stage for increased payload capability and maneuvering. The number of modules will vary from one to three. The propulsion system will use high pressure bell engines of Pratt and Whitney design. The propellants will use LOX/LH_2.

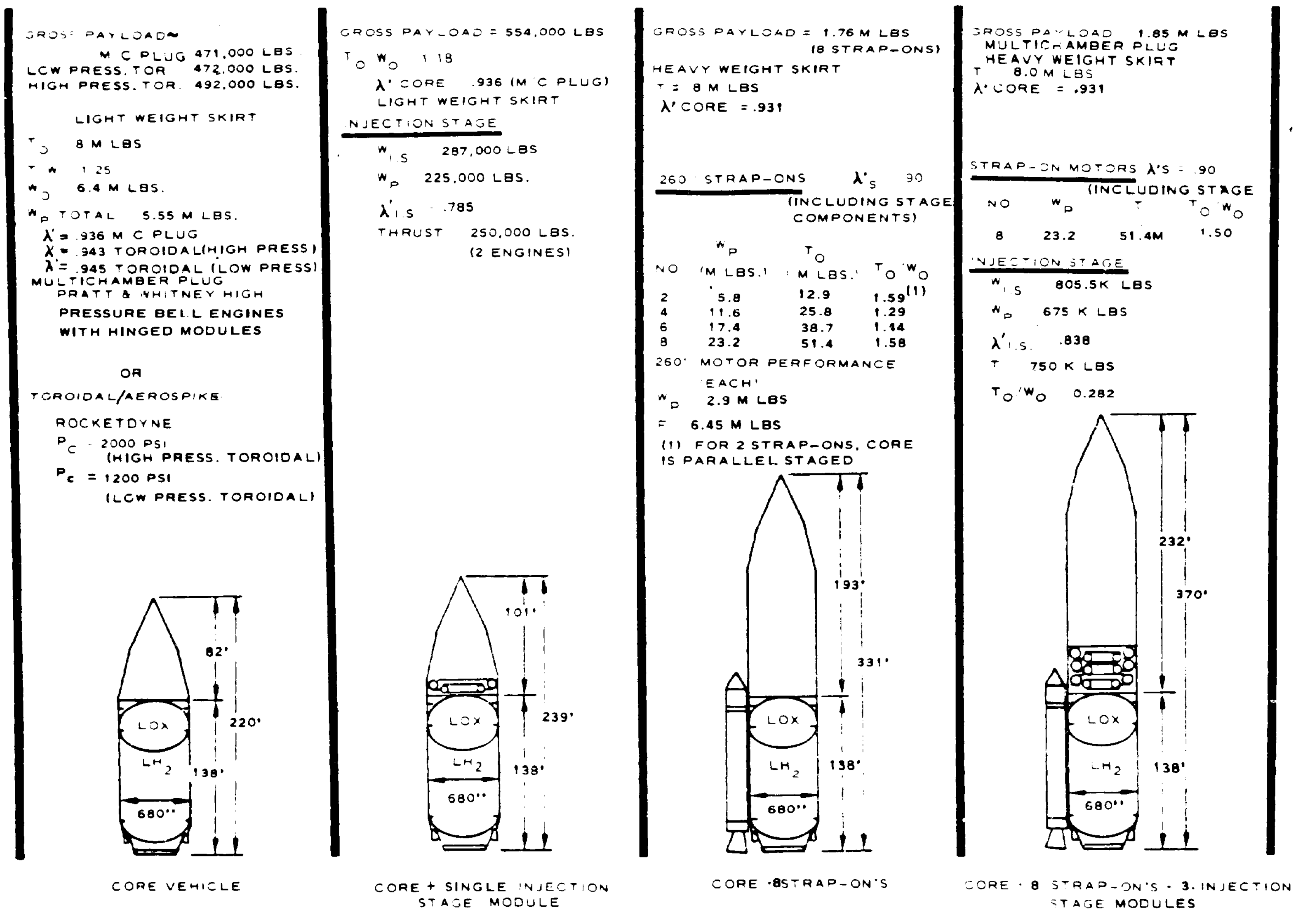
c. Strap-On Stages - Sized to provide a payload to a 100 N.M. orbit of approximately 2, 000, 000 pounds when used to augment the main stage with injection stage modules. Solid rocket motors of 156 inch and 260 inch diameters were considered.

The baseline MLLV vehicle family is depicted in Figure 1. 0. 0. 0-3. Payload performance for this family is summarized in Figure 1. 0. 0. 0-4.

This volume, Cost Implications of Vehicle Size, Technology Configuration and Program Options, presents an assessment of and applications for the overall study results. The detailed cost analyses developed for the AMLLV and the MLLV and reported in Volumes IV and V were utilized to conduct cost effectiveness and parametric analyses of program, configuration, size and technology alternatives.

This volume is divided into eight sections. The first two sections outline and summarize the remaining sections of the document. Section 3. 0 presents the objectives, ground rules, guidelines and assumptions. As the cost data presented here were strongly influenced by the utilization of specific design, resources and cost ground rules, these ground rules (which were also reported in previous volumes) are contained herein for ready reference. Section 4. 0 presents the cost magnitudes and distributions relative to program phases, vehicle stages and elements, and cost categories. The effects of learning curves on the recurring costs of the various vehicle components are tabulated for both the AMLLV and the MLLV families. Methods for obtaining program cost for a specific vehicle configuration or for a series of vehicles in a program are illustrated by representative examples.

Section 5. 0 illustrates the method of using the cost information to determine the cost effectiveness of the program and configuration options. Overall program costs are shown for different program sizes utilizing different vehicles of both the AMLLV and the MLLV configurations. The cost impact of providing manufacturing, test and launch facilities for the largest vehicle configuration (and then utilizing the same facilities for a full range of vehicle configurations in the vehicle family)



* ALL PAYLOADS SHOWN FOR ρ 5 LBS FT^3 100 NAUTICAL MILE CIRCULAR ORBIT

FIGURE 1.0.0.0-3 HALF SIZE (MLLV) BASELINE VEHICLE FAMILY

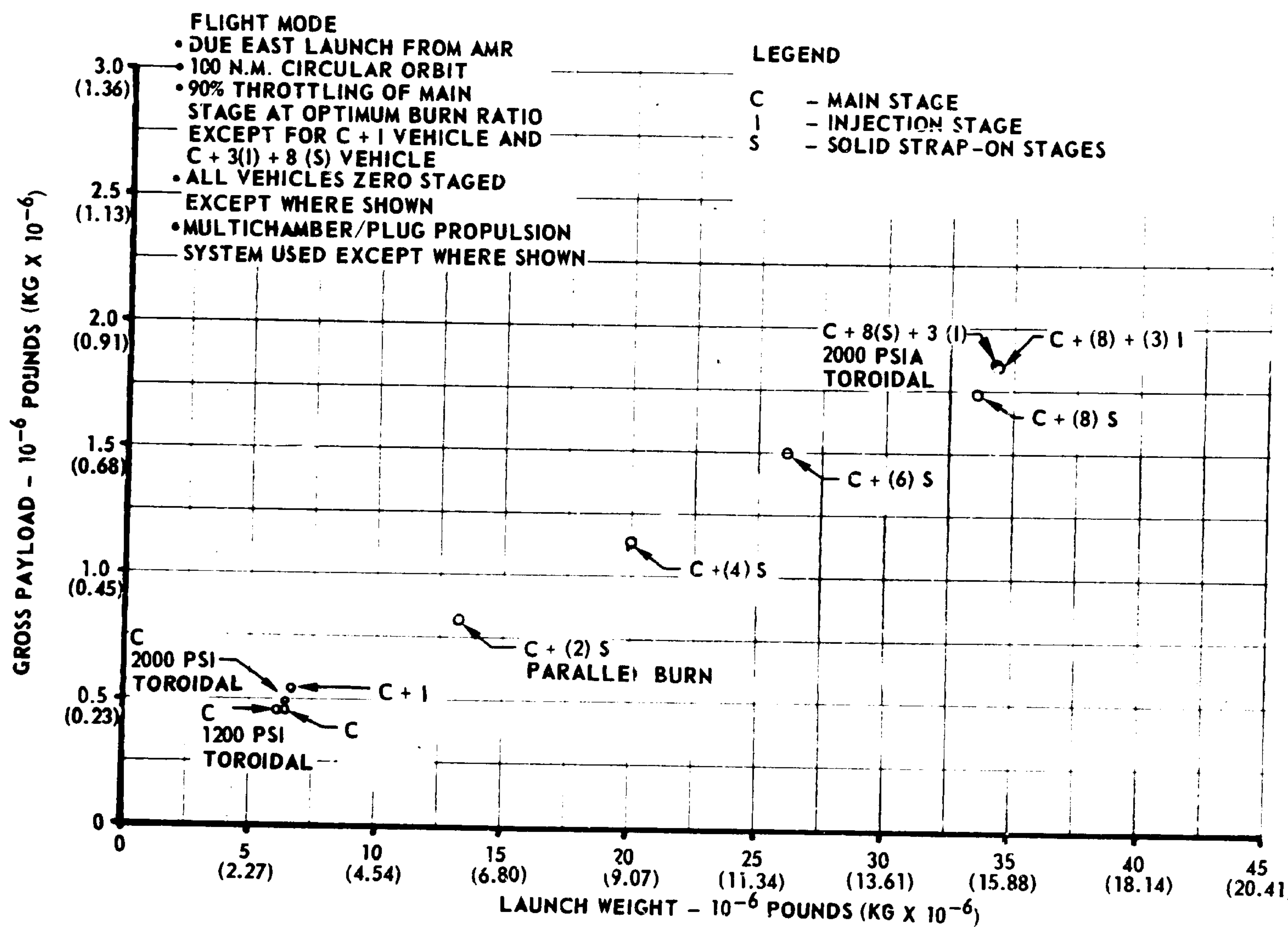


FIGURE 1.0.0.0-4 MLLV PAYLOAD VERSUS LAUNCH WEIGHT

1.0 (Continued)

is compared to costs for providing similar facilities sized for a specific vehicle configuration. The effects of the manufacturing and launch rate on overall program cost, estimated on the basis of historical data on the Saturn V program, are presented. Performance and cost potential of various main stage engine options, including various configurations of the multichamber/plug propulsion system and the toroidal/aerospike propulsion system are discussed. Other propulsion system trades, as presented, included the use of liquid strap-on stages versus solid propellant strap-on stages, the use of 156 versus 260 inch solid propellant rocket motor stages and the effect of staged 260" SRM stages versus non-stages 260" SRM stages.

Section 6.0 contains the methodology for cost effectiveness evaluation of alternative technology applications. Parametric data which can be used to determine whether the development of advanced technology is cost effective is presented. Technology improvements are related to either improved mass fraction (weight improvements) or propulsion performance (I_{sp}). Parametric cost curves as a function of performance, size, etc., for the baseline vehicles are shown. Costs of the major baseline vehicle components (structure, engines, propellant, subsystems, etc.) are defined or modeled in terms of dollars per pound of baseline vehicle dry weight or launch weight. The resulting parametric curves and associated data are used in representative examples to assess the cost-effectiveness of potential technology improvements.

Section 7.0, Risks and Deletions, contains an estimation of those activities and program options which may be deleted from the program thus improving the cost effectiveness. With these deletions, of course, a greater risk is assumed. These have been placed in order of probable increasing risk.

Section 8.0, Program Managers Assessment, presents a critical review of the data and study results by the program manager and the members of the study team.

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2.0 SUMMARY

This volume presents a critical assessment of the overall study results to provide an understanding of the cost implications of launch vehicle size, technology, configuration and program options.

2.1 COST DISTRIBUTIONS AND SIZE IMPLICATIONS

To define the relative cost relationships for development, procurement, and operation of the baseline MLLV and AMLLV families, the "modularized" costs (and supporting resource data) of the two vehicle families were collected and categorized, during the course of the study activity, by three program phases, i.e.:

Phase A "Get Ready" Phase

This category includes non-recurring costs for vehicle design, and for the tooling, equipment and facilities required for production and launch.

Phase B Development Test Phase

This category includes the non-recurring costs for all development test activity required to develop and qualify the launch vehicle, its components and the associated support hardware for manned flight.

Phase C Operational Program Phase

This category includes all of the recurring costs for manufacture and launch of the operational vehicles.

The distributions of program costs showed that the percentage of overall program costs attributable to each of these phases was approximately the same for both the AMLLV and MLLV programs. This is indicative that the relative distribution of costs by program phase will be independent of vehicle size. Generally, the non-recurring costs (the sum of the A and B costs) will be approximately 11 times those of the first operational unit cost. The Phase A costs will be approximately 4 1/2 times and the Phase B costs will be 6 1/2 times those of the first operational unit, respectively. The relative distribution of costs by program phase does not appear to be sensitive to complexity, as the relative distribution of the costs for the three program phases were generally the same for the main stage, the injection stage and the solid rocket motor strap-on stages.

Magnitude of overall cost appears to be primarily influenced by the complexity of the structure or system to be built and secondarily influenced by the difference in size. For example, the cost for the injection stage module will be approximately

2.1 (Continued)

the same as that for a strap-on solid rocket motor (SRM) stage even through the weight of an individual SRM stage will be approximately seven times that of a fueled injection stage module.

The overall magnitude of the costs will be significantly larger for the main stage as the main stage not only is the more complex stage but is also the primary stage of the launch vehicle and, therefore, must absorb a significant portion of the costs for program management, system engineering, launch facilities and liquid stage manufacturing and test facilities.

Further, the magnitudes of the costs in Phases A, B, and C will not be significantly sensitive to the relative size of similar articles. For example, the half size (MLLV) main stage costs for these phases will be approximately 85 percent those of the full size (AMLLV) main stage.

The magnitude of component costs in Phases A and C will, however, be more nearly directly related to the quantity required per operation vehicle. For example, the magnitude of engine and SRM costs per vehicle will be almost directly related to the number required per vehicle.

The magnitude of the component costs for Phase B will not be sensitive to the quantity required per vehicle. For example, the development test costs for the SRM stage will be approximately the same regardless of the quantity to be used per vehicle.

As will be discussed subsequently, the magnitude of the A and C costs for a vehicle program will be strongly influenced by the anticipated production and launch rate. The magnitude of the development test or B costs, however, will be insensitive to the anticipated production and launch rate.

The two R&D flight tests specified for the development test program will represent approximately 25% of the overall non-recurring costs required for either of the two vehicle systems. If useful payloads could be flown on the R&D test flight vehicles, program costs could be substantially reduced.

The addition of either injection stages or SRM stages to the primary main stage will not significantly increase the magnitude of the non-recurring program costs. For example, non-recurring costs for the main stage alone will be 86 percent of those for the main stage and SRM stages.

2.1 (Continued)

The distribution of Phase A costs by cost categories (i.e., manpower, material, tooling, facilities and equipment) indicates that a significant portion of the A costs will be attributable to facilities and equipment. The next largest cost category will be tooling. The tooling costs will be the most sensitive cost category relative to vehicle size, even though they will be reduced by only 28 percent as the vehicle size is reduced by 50 percent.

A major portion of the Phase A costs will be involved in the provision of the launch facility. These costs will represent approximately 45 percent of the total get ready costs for the MLLV and AMLLV single-stage-to-orbit vehicles. As the injection stage will be the same diameter as the main stage, and will fit atop the main stage without significantly increasing the length of the vehicle, its effect on launch facility costs will be negligible. For use of the SRM strap-on stages, however, a significant increase in the launch facility will occur.

The relative distribution of costs by program cost categories and elements (i.e., structures, engines, systems, etc.) will be generally the same as that of the two stage Saturn V for both the MLLV and AMLLV single-stage-to-orbit vehicles. The engine systems, however, for the AMLLV and MLLV vehicles will represent a larger percentage of the overall operational program costs than do those of the Saturn V. This is attributable to the number of engines involved. For the MLLV and the AMLLV, 24 individual engines will be used for each main stage. By comparison, the two stage Saturn V has a total of 10 engines for both stages.

2.2 COST EFFECTIVENESS OF PROGRAM AND CONFIGURATION OPTIONS

The specific payload requirements, in terms of required payload weight per launch will have a major influence on the choice of the vehicle configuration to provide the most cost effective program. However, the cost per pound of delivered payload generally will decrease as the required payload weight per launch is increased. In other words, the lower payload single-stage-to-orbit vehicles will be the least cost effective vehicles in the MLLV and AMLLV families. Cost effectiveness will improve as SRM strap-on rocket motors are added to the main stage.

Only small operational programs will be required to amortize the additional non-recurring costs for development and implementation of the strap-on stages (i.e., programs requiring three million pounds of payload to orbit for the MLLV and six million pounds of payload to orbit for the AMLLV).

Use of the injection stage as a propulsive element to increase payload to a 100 N.M. orbit will never be as cost effective as utilization of the SRM strap-on stages or an increase in the size of the main stage. For this reason, use of the injection stage should be considered only, after achievement of orbit, for payload maneuvering or for missions beyond earth orbit. (The injection stage should be considered

2.2 (Continued)

as part of the payload to orbit rather than as part of the propulsion system to achieve orbit.)

The operational cost effectiveness values of all of the possible configurations in the MLLV family were compared (1) to those of configurations in the AMLLV family and (2) to those of the two stage Saturn V vehicle and its potential uprated derivatives employing 156 inch and 260 inch diameter SRM strap-on stages. This comparison lead to the very significant study conclusion that, for a given payload per launch requirement, operational costs will not be significantly influenced by the choice of any specific launch vehicle configuration with the capability of providing the required payload. Operational costs do not appear to be sensitive to design or configuration options. (Costs are, however, sensitive to payload size as discussed below.) This conclusion assumes that all possible configurations will be produced and operated within the same program philosophy, limitations and ground rules.

The data showed that improved cost effectiveness (as stated above) will be obtained as the payload per launch requirement in increased. In other words, there appears to be a "quantity discount" relative to larger sized payloads. This quantity discount is based on the assumption that whatever size vehicle is used, the same production and launch rate will be maintained.

This study, as well as prior experience with the Saturn V and other programs, showed that the cost of a launch vehicle will be significantly effected by the production and launch rate. A primary factor causing increased cost at low rates is the inflexibility within the current manufacturing and launch philosophy relative to the use of personnel and skills. The costs for a full complement of personnel and skills, (required at the production and launch facilities regardless of the rate) will significantly increase the unit cost at low rates. A major factor in reducing costs would be an increase in the production and launch rate from approximately two vehicles per year to approximately six vehicles per year.

The cost trades of engine options showed that program costs were only slightly effected by the various possible adaptations to either the multichamber/plug or toroidal/aerospike engine systems in terms of size of the engine systems, operating pressure, number of modules, etc.

The engine option trades indicated that lower operational cost will result from the use of the larger and/or higher performance engine options with both the single-stage-to orbit vehicles and vehicles containing strap-on stages. For example, operationally it will be more cost effective to use the higher performance 2000 psi toroidal/aerospike engine with eight modules, each rated at 2 million pounds thrust than to use the lower performance 1200 psi modules rated at 2 million pounds thrust or the higher performance 2000 psi toroidal/aerospike engine with 16 modules rated at 1 million pounds thrust each.

2.2 (Continued)

The above conclusion assumes a moderate or large operation. However, for small operational program sizes which cannot effectively amortize the higher non-recurring cost of the larger higher performance systems, the lower performance, lower thrust, systems will be more cost effective.

If low cost liquid stages can be developed and procured at the same price as the SRM strap-on stages, a minor reduction in program cost will occur, attributable to easier transportation and handling of the lighter weight (empty) liquid stage. The transportation and handling costs for use of either of these stages will be so nearly the same, however, that no significant cost advantages can be attributed to either system.

The use of 260 inch diameter SRM's will be more cost effective than the use of equivalent performance 156 inch diameter SRM's for an operational program. Although the non-recurring costs for the 156 inch SRM's will be less than that of the 260 inch SRM's, the lower production costs of the 260 inch SRM's will make them become more cost effective as program size increases. Again, as with the liquid engines, the cost trades tend to favor the larger sizes over the smaller sizes.

The baseline program calls for use of the solid rocket motor strap-on stages in a "zero" stage mode wherein all of the SRM's will be ignited at liftoff and separated at the same time after burn out. A sequential staging concept such that approximately 3/4 of the quantity of SRM's would be ignited at launch and the remaining 1/4 ignited after burnout of the initial 3/4 would in effect provide a three stage vehicle and increase the payload capability by better than 10%. This alternative concept would only slightly increase the program cost but would provide a significant improvement in payload and, therefore, is an attractive option for the vehicle system.

2.3 COST EFFECTIVENESS OF ALTERNATE TECHNOLOGY APPLICATIONS

Parametric cost and performance data and its application show the maximum dollars that can be spent for an alternative technology for any specified vehicle program. These data (1) relate the required main stage size for a given payload to specific impulse and mass fraction, and (2) show the relationships of program cost to main stage size.

The data relative to improvements in structural efficiency indicate that the programs with single-stage-to-orbit vehicles will be more cost sensitive to improvement or degradation in mass fraction than those programs employing vehicles with strap-on stages. Similar analyses showed that the AMLLV and MLLV single-stage-to-orbit

2.3 (Continued)

configurations will be more cost sensitive to changes in specific impulse than will configurations with strap-on stages.

Application of the mass fraction and specific impulse changes show the following cost effects for a program to place 20 million pounds of payload in orbit. For the AMLLV single-stage-to-orbit vehicle, a 0.02 improvement in mass fraction will result in a program cost reduction of seven percent. Similarly, a five percent improvement in specific impulse will reduce the program costs by five percent. A degradation of five percent in specific impulse will increase the program cost 6.5 percent.

2.4 COST REDUCTION ANALYSIS

Cost reduction of the baseline programs can be achieved through configuration modifications and/or changes in program philosophy relative to design, manufacturing, and test and launch. Changes in program philosophy will, however, be much more effective in reducing costs. Philosophy changes include such things as utilization of the two R&D flights to deliver unmanned but useful payloads; modification to the manufacturing and launch procedures used with low production and launch rates, to provide more effective utilization of personnel and skills; deletion of the facility checkout vehicle (the first R&D flight vehicle would be used for facility checkout); reduction in instrumentation; deletion of redundant components; reduction of post-manufacturing checkout; deletion of dynamic tests; deletion of static firing acceptance tests; reduction of tolerances; and reduction of the safety factor from 1.40 to 1.25. (The above are listed in order of increasing risk as the list progresses.)

A cost reduction of approximately 40% appears possible for a typical program to develop and launch 36 MLLV single-stage-to-orbit vehicles. The resource and cost analyses of this study were accomplished on the basis of the existing techniques utilized for the Saturn V launch vehicle. Similar cost reduction methods have been proposed for the Saturn V but have yet to be implemented.

3.0 GROUND RULES, GUIDELINES AND ASSUMPTIONS

The guidelines and assumptions for this study were developed from the contractual requirements, the previous AMLLV study (NAS2-4079), and applicable data from previous and current studies. Where special circumstances dictated an arbitrary assumption, The Boeing Company and the NASA technical monitor concurred on a suitable guideline.

The resource plans were based on current Saturn V philosophies to the maximum extent possible. No attempt was made to tailor the program for cost optimization.

Where possible, the cost estimates were based on direct costs with burden costs added as separate items.

Resource inputs for recurring and non-recurring items were received from functional organizations within The Boeing Company and from propulsion contractors (Aerojet General, Pratt and Whitney, and Rocketdyne). Most of the direct inputs were in terms of manhours; however, total dollar costs were also received for several items, i.e., material, equipment, engines, etc.

The Boeing Manufacturing Departments at the Michoud Assembly Facility and at Huntsville provided manhours and material estimates for the following items: 1) Fabrication, Major and Minor Assembly of the Sub-System Components, 2) Manufacturing Test Manhours, 3) Raw and Production Material, 4) Planning manhours, 5) Tool Design manhours, 6) Tool Fabrication and Erection hours, 7) Manufacturing Development hours, and 8) MGSE and Handling/Transportation Equipment hours and dollars.

The Boeing Huntsville Engineering Department provided basic engineering design and sustaining engineering manhours. The Boeing Facilities Department at Huntsville, BATC and Michoud provided costs of the brick, and mortar facilities for production, test and launch; transportation and handling equipment; capital equipment and maintenance costs. The Boeing Test Organization at Huntsville provided manhours and costs for conducting Developmental Testing, Structural Tests, Systems Development (Systems Breadboard), Systems Tests, Dynamic Tests, Manufacturing Development and Wind Tunnel Tests.

The Boeing Engineering Department at BATC provided costs for Launch Operations and Launch Vehicle Ground Support Equipment (LVGSE) and Test Equipment.

The propulsion contractors provided costs for the solid rocket motors, toroidal/aerospike engine and the multichamber/plug engines. The liquid engine data was supplemented with data received from the Propulsion Office at NASA/MSFC.

3.0 (Continued)

The details associated with these direct inputs are displayed and summarized in the "Resources Implications" Volume III of this report.

The following ground rules, guidelines, and assumptions were utilized for this study activity, "Cost Studies of Multipurpose Large Launch Vehicles" Contract NAS2-5056:

a. Design

1. Direct ascent to 100 nautical mile circular earth orbit was the primary mission used to size and establish the baseline vehicle design, to establish the trajectory for heating and control analyses, and as the reference for performance comparisons.

2. The vehicles will be launched due east from AMR.

3. Payload configurations will be as follows:

   a. The payload, exclusive of the nose cone, will have a constant diameter.

   b. Uniform distribution of mass within payload envelope was assumed.

4. Stages and vehicle subsystems will be expendable.

5. All study vehicles will be manrated. The design criteria and the necessary combination of ground and flight testing were defined based on those established for the Saturn IB/Gemini and Saturn V/ Apollo systems.

b. Test

1. Present NASA/MSFC and KSC test philosophies will be continued.

2. Two R&D flight tests will be required to qualify the vehicle. The development test program for either the AMLLV or the MLLV will provide for two unmanned flight tests of the maximum size configuration in the selected vehicle family.

3.0 (Continued)

3. A facility checkout vehicle will be provided for initial checkout of the manufacturing, test, and launch operations, tooling, equipment and facilities.

4. A dynamic test will be included in each program (either AMLLV or MLLV) for the maximum size vehicle (strap-ons will be simulated).

5. Development testing of the main stage and injection stage will be conducted in new dynamic and structural test facilities constructed adjacent to the factory building.

6. The solid motors will require a development program and qualification testing.

7. Engine acceptance test firing and trim by engine contractor will be required.

8. Static test firing will be required for final acceptance of the main stage and injection stage.

9. Static test firing will be conducted on the launch pad.

10. All subsystems functional and acceptance testing will be performed by the vendor except as noted.

c. Manufacturing

1. All stages will be built in factories adjacent to navigable waterways.

2. Main stages and injection stages will be fabricated at the NASA Michoud site (or its equivalent located on a navigable waterway) in a new factory building.

3. The 260 inch diameter solid rocket motors (SRMs) will be manufactured at the Aerojet General Facility in Dade County, Florida.

4. The 260 inch SRM strap-on stage structural assemblies, consisting of the nose cone, forward skirt, aft skirt and attachment fittings will be fabricated at Michoud and sent to the SRM contractors facility at Homestead, Florida for assembly to the solid rocket motor.

d. Transportation

1. The vehicle elements will be transported from the manufacturing facilities to the launch facility on towed barges.

3.0 (Continued)

2. Land transportation will be required for the main and injection stages at the manufacturing facility (but not at the launch site).

3. At the launch facility all stages will be lifted directly off their barges and placed in the selected location by a large traveling gantry hoist; therefore, no additional transportation equipment will be required.

4. The requirements for transporting and handling the elements of the half size (MLLV) vehicle will be the same as those of the full size (AMLLV).

5. No land transportation of the SRM stage will be required, as it will be lifted directly from the manufacturing pit and placed aboard the towed barge used for transport to the launch facility.

6. The barges used to transport the SRM stages from the manufacturing site to the launch pad will also serve as storage facilities. These barges will be anchored in protected, yet remote locations, and towed to the launch pad as required for vehicle assembly.

7. At the launch site, the SRM's will be lifted directly from the barge and placed in position on the launch pad by a mobile overhead gantry crane. This same track mounted gantry will also be used to lift the main and injection stages.

e. Launch

1. The launch pad will serve as the static firing stand for main and injection stages, the refurbishment facility, the vertical assembly and checkout facility and finally the launch pad.
2. The launch site will be in the vicinity of Cape Kennedy to share the utilization of the available support facilities, support personnel, and existing tracking networks.

3. Although the acoustic siting criteria indicate that an off-shore site is required, an on-shore site was specified to provide comparable facility, equipment, tooling and cost requirements to those of existing systems.

4. Mating of the SRM and injection stages to the main stage will be at the launch pad. Final vehicle assembly and checkout will be in the launch position.

3.0 (Continued)

f. Cost

1. All propulsion costing, performance, and design data necessary in the evaluation were compiled from appropriate propulsion contractors (i.e., the contractors specifically working on the respective systems).

2. Costs were based on 1968 dollars without an inflationary factor. Funds were assumed to be available as required.

3. Launch and production rates will be two vehicles per year.

4. All cost values in this report are contractors cost values only and do not include profit or fee, with the exception of the Solid Rocket Motors and liquid engines.

5. The first unit has been defined as the first flight vehicle: (the first R&D flight test) effects of learning curve(s) enter after that unit.

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4.0 COST DISTRIBUTIONS, SIZE IMPLICATIONS, LEARNING CURVE EFFECTS AND METHODS FOR COMPILING PROGRAM COST

This section summarizes the input cost data and shows the distribution of costs by 1) program phases, 2) vehicle stages and elements, and 3) cost categories. The implications of vehicle size on the costs and their distribution are illustrated and discussed. The effects of learning on recurring costs are tabulated and graphically illustrated to provide tools for conducting cost effectiveness analyses as discussed in subsequent Sections 5.0 and 6.0. Methods are given for compiling overall program costs.

The "modularized" cost data shown in detail in Volumes IV and V are summarized by program phases and stage and program elements in Figures 4.0.0.0-1 through 4.0.0.0-3. The costs shown are additive i.e., the Phase A costs for an MLLV vehicle incorporating a main stage plus an injection stage engine module plus two injection stage fuel modules plus four strap-on stages can be determined by adding the main stage costs (Column I) plus the injection stage engine module costs (Column II) plus twice the injection stage fuel module costs (two times Column III) plus the strap-on stage fixed cost (Column IV) plus one-half the variable cost of eight strap-on stages (one-half of Column V). The same addition is possible to determine the program buildup for Phase B costs. To determine the overall program costs for Phase C, however, learning effects must be applied to the multiples of stages required for the program. These effects and their application are shown and discussed in Sections 4.2 and 4.3.

The results of adding the various elements (with appropriate learning curve factors as applicable) to determine Phase A, B and C costs are summarized in Figure 4.0.0.0-4. This chart shows, for example, that the total non-recurring costs (Phase A costs plus Phase B costs) for an MLLV vehicle consisting of a main stage plus eight SRM stages plus a three module injection stage will be 4.09 billion dollars. The recurring cost of the first operational vehicle will be 372 thousand dollars. Similarly, the recurring cost of the first operational MLLV single-stage-to-orbit vehicle will be 251 thousand dollars. The non-recurring costs for development of this vehicle (not shown on figure) will be 2.78 billion dollars.

4.1 COST DISTRIBUTIONS AND VEHICLE SIZE IMPLICATIONS

The detailed "modularized" cost data shown in Volumes IV and V were analyzed to determine the distribution of costs relative to:

a. Program Phases

1. "Get Ready" costs (A costs)
2. Development test costs (B costs)
3. First operational unit costs (C costs for the 3rd flight unit)

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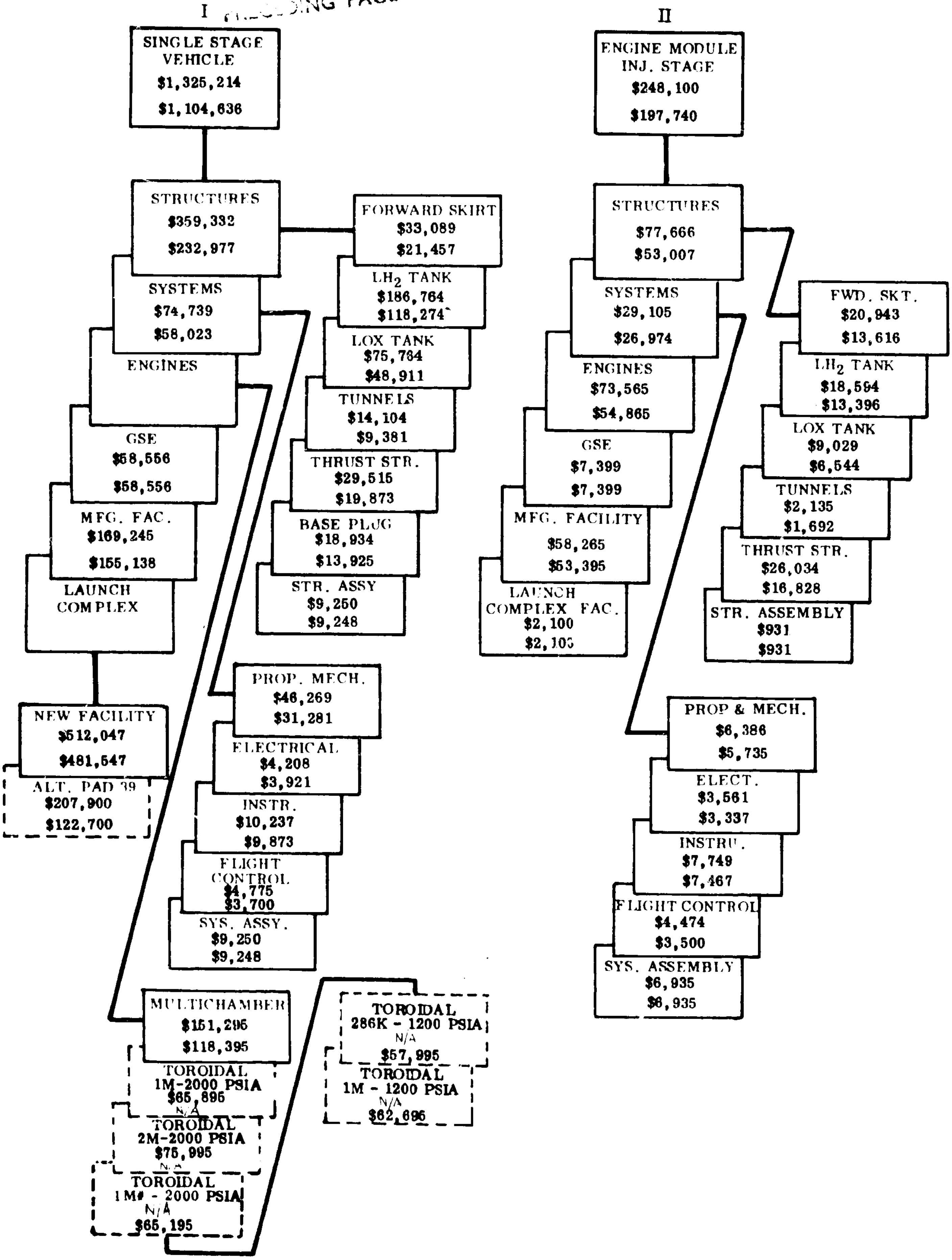

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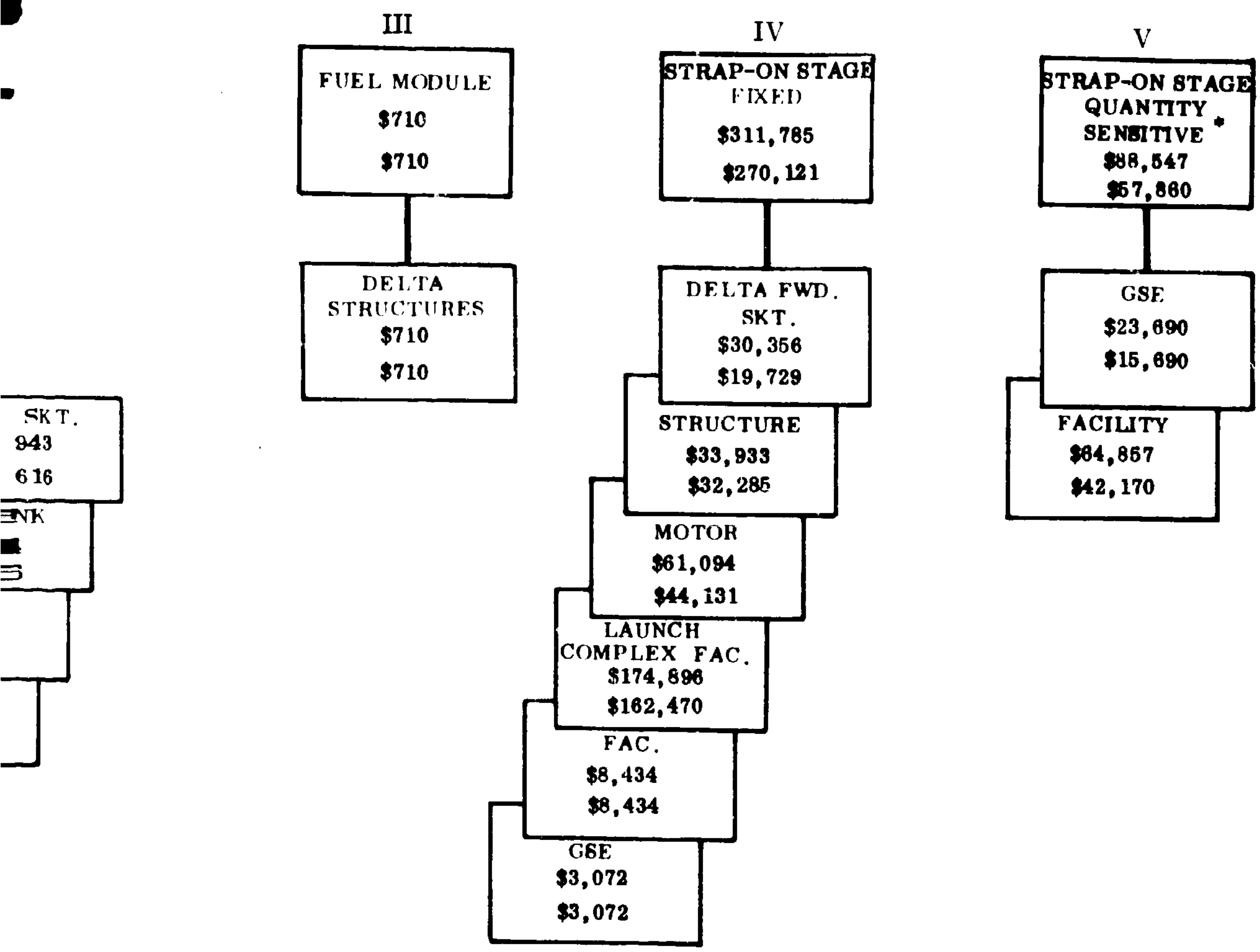
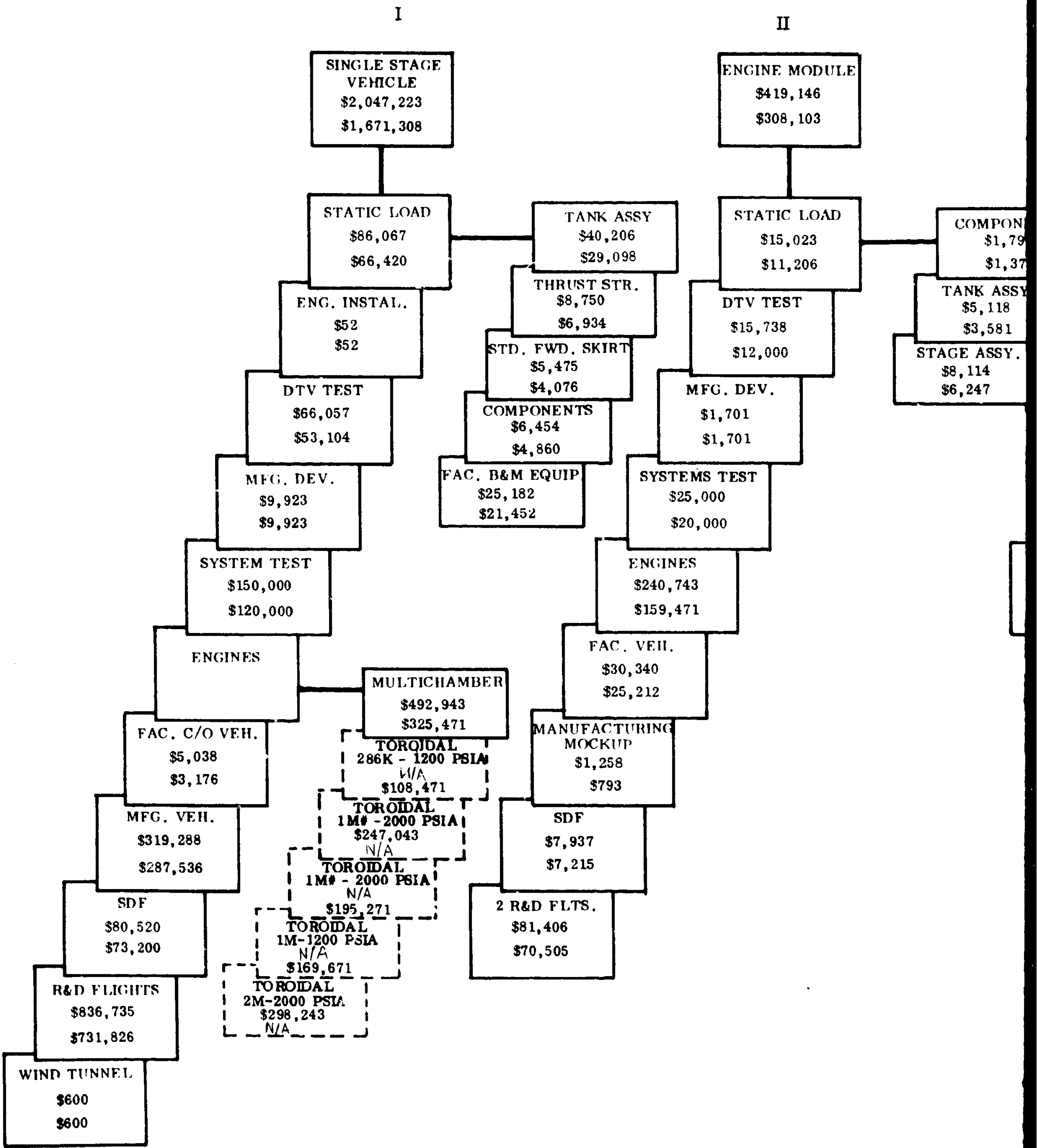


NOTES: [- - - - -] ALTERNATE SYSTEMS.

- DOLLARS ARE IN THOUSANDS.
- AMLLV COST SHOWN ON TOP
- MLLV COSTS SHOWN ON BOTTOM

*NOS. SHOWN ARE FOR A FULL COMPLEMENT (12 OR 8) OF STRAP-ON STAGES. IF LESS THAN A FULL COMPLEMENT WILL BE USED, THESE NOS. SHOULD BE REDUCED BY THE RATIO OF THE NUMBER OF STRAP-ON STAGES PER VEHICLE TO THE NUMBER OF STRAP-ON STAGES IN A FULL COMPLEMENT

FIGURE 4.0.0.0-1 "GET READY" COST ("A" COST) SUMMARY



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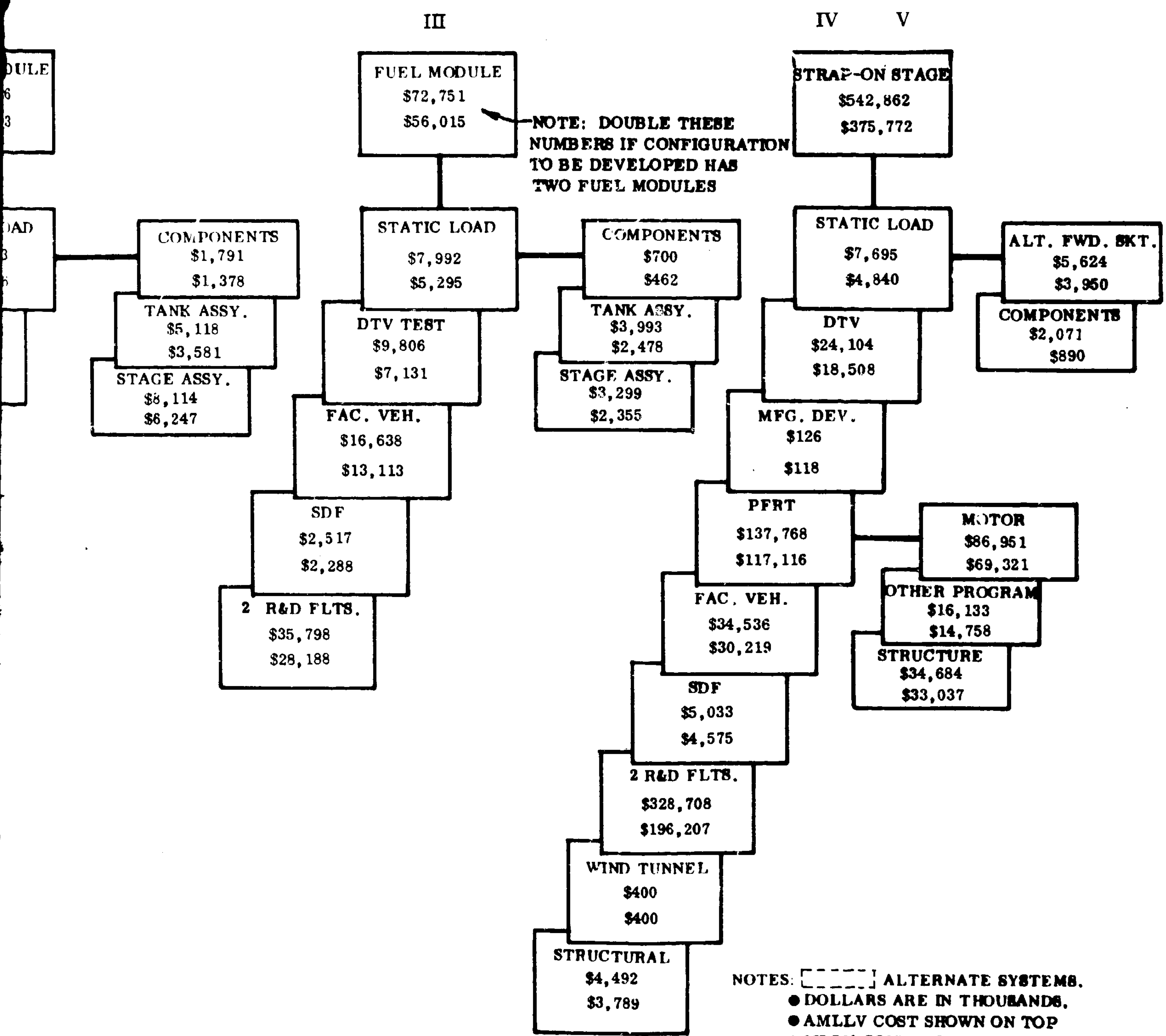
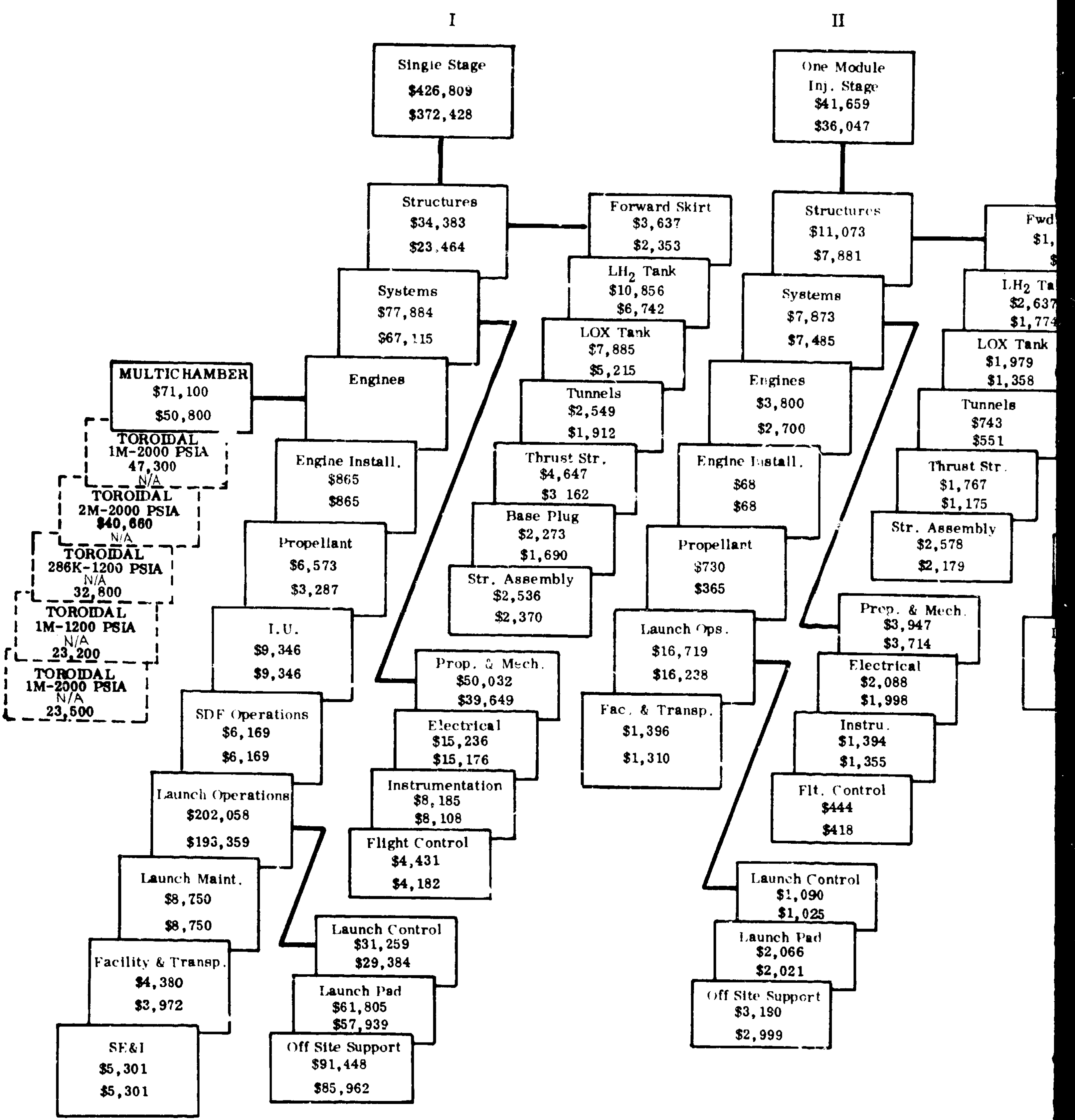


FIGURE 4.0.0.0-2 DEVELOPMENT TEST COST ("B" COST) SUMMARY



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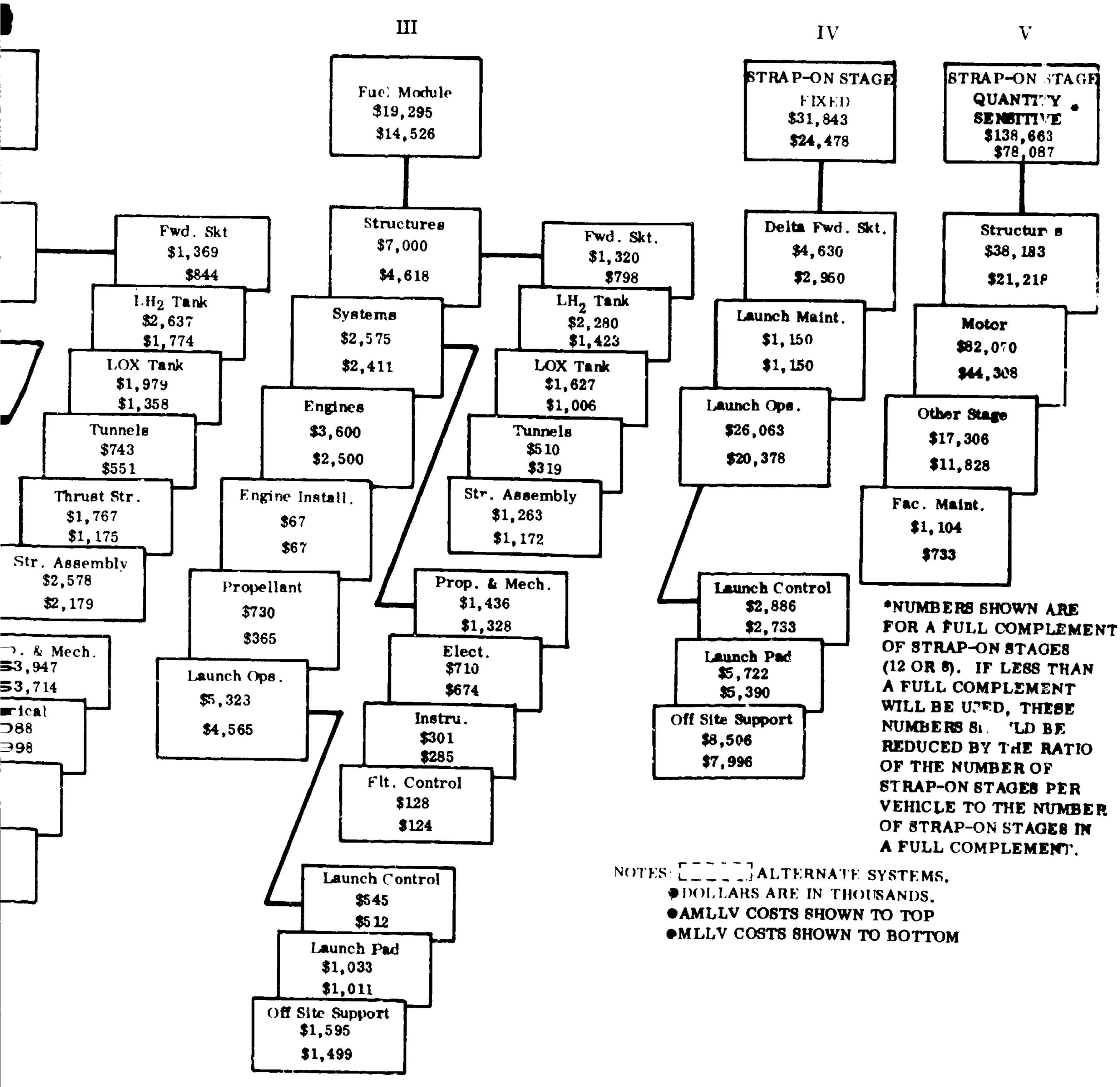


FIGURE 4.0.0.0-3 FIRST UNIT COST ("C" COST) SUMMARY (APPLICABLE TO FIRST R&D FLIGHT VEHICLE ONLY)

(DOLLARS IN BILLIONS)

	MAIN STAGE	THREE MODULE INJECTION STAGE	FULL COMPLEMENT OF STRAP-ON STAGES	2 R&D FLIGHTS	TOTAL
GET READY "A" COSTS	$1.104 / $1.325	$.198 / $.249	$.328 / $.400	N/A / N/A	$1.630 / $1.974
DEVELOPMENT TEST "B" COSTS	$.939 / $1.210	$.294 / $.413	$.180 / $.214	$1.049 / $1.313	$2.462 / $3.150
TOTAL NON-RECURRING	$2.043 / $2.535	$.492 / $.662	$.508 / $.614	$1.049 / $1.313	$4.092 / $5.124

1ST OPERATIONAL VEHICLE "C" COST (THIRD FLIGHT UNIT)	$.251 / $.293	$.043 / $.055	$.078 / $.138	N/A / N/A	$.372 / $.486

NOTE: MLLV COSTS / AMLLV COSTS

FIGURE 4.0.0.0-4 COST SUMMARY - AMLLV/MLLV BASELINE FAMILY

4.1 (Continued)

b. Program Elements

1. Stage costs - Main stage, injection stage, strap-on stage, etc.
2. Component costs - Structures, propulsion and mechanical, electrical and electronic, etc.
3. Operations costs - Manufacturing, test, transportation, launch, etc.

c. Cost Categories

1. Labor
2. Material
3. Tooling
4. Equipment
5. Facilities

The resulting data is summarized in Figures 4.1.0.0-1 through 4.1.0.0-10. Figure 4.1.0.0-1 shows the apportionment of stage costs by program phases. Figure 4.1.0.0-2 shows the stage cost distribution by program phases for the maximum size AMLLV and MLLV vehicles. These figures indicate that the costs for the main stage development and operation with an MLLV or AMLLV maximum size(1) vehicle will be approximately two-thirds of the total A, B and/or C costs. Costs for the three module injection stage and for the full complement of strap-on stage will be approximately one-fifth and one-eighth of the total costs respectively.

The majority of the costs are attributable to the main stage because the main stage is the primary stage of the launch vehicle and, therefore, must absorb a significant portion of the fixed program costs associated with:

a. Program Management and System Engineering.

b. Liquid stage manufacturing and test facilities (construction, checkout, operation and maintenance).

c. Launch facility (construction, checkout, operation and maintenance).

The apportionment of costs by program phases and stages provided the following relationships:

	MLLV	AMLLV
a. Main Stage		
$\frac{A}{C \text{ (3rd Flight Unit)}}$	4.40	4.52

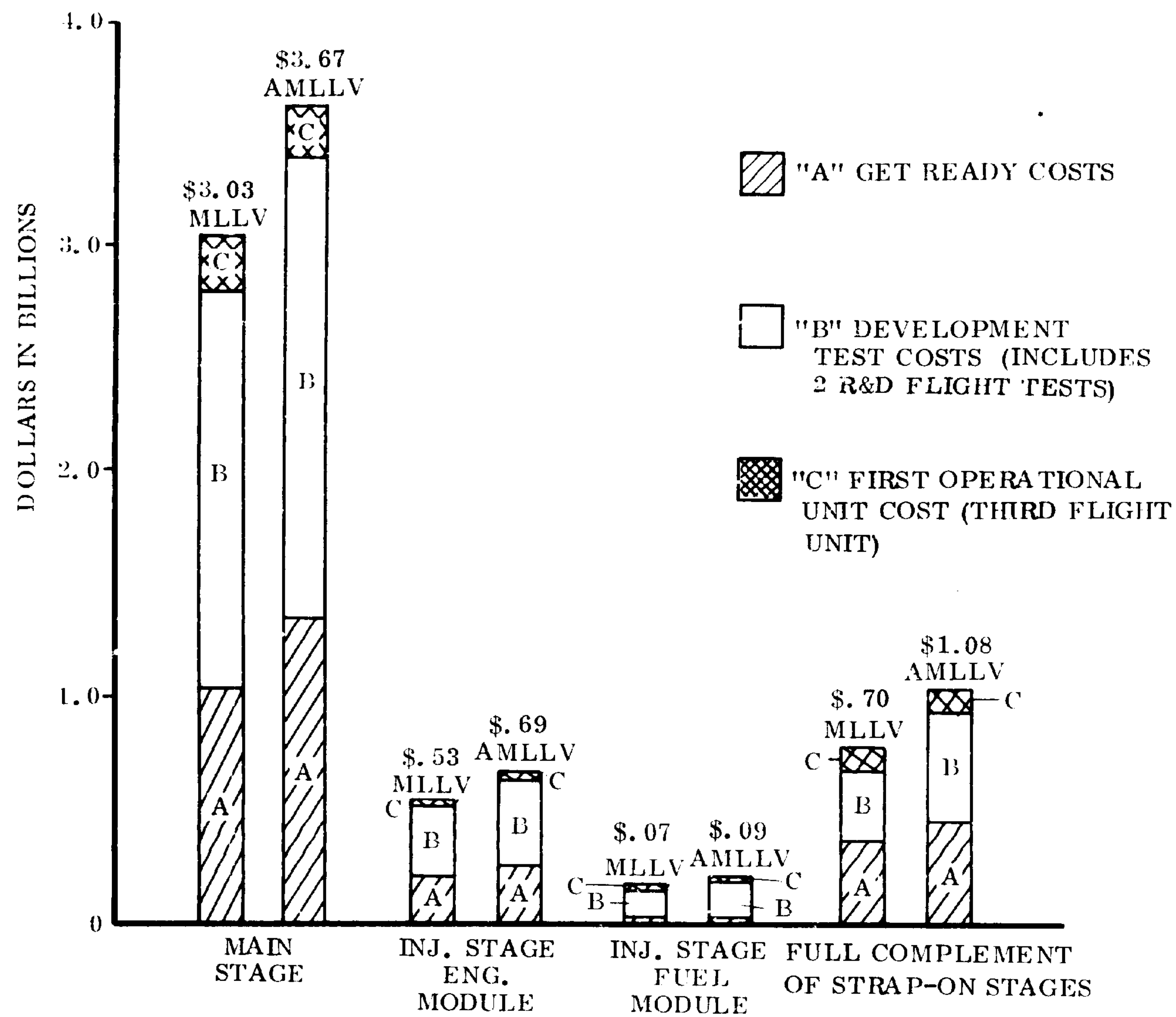
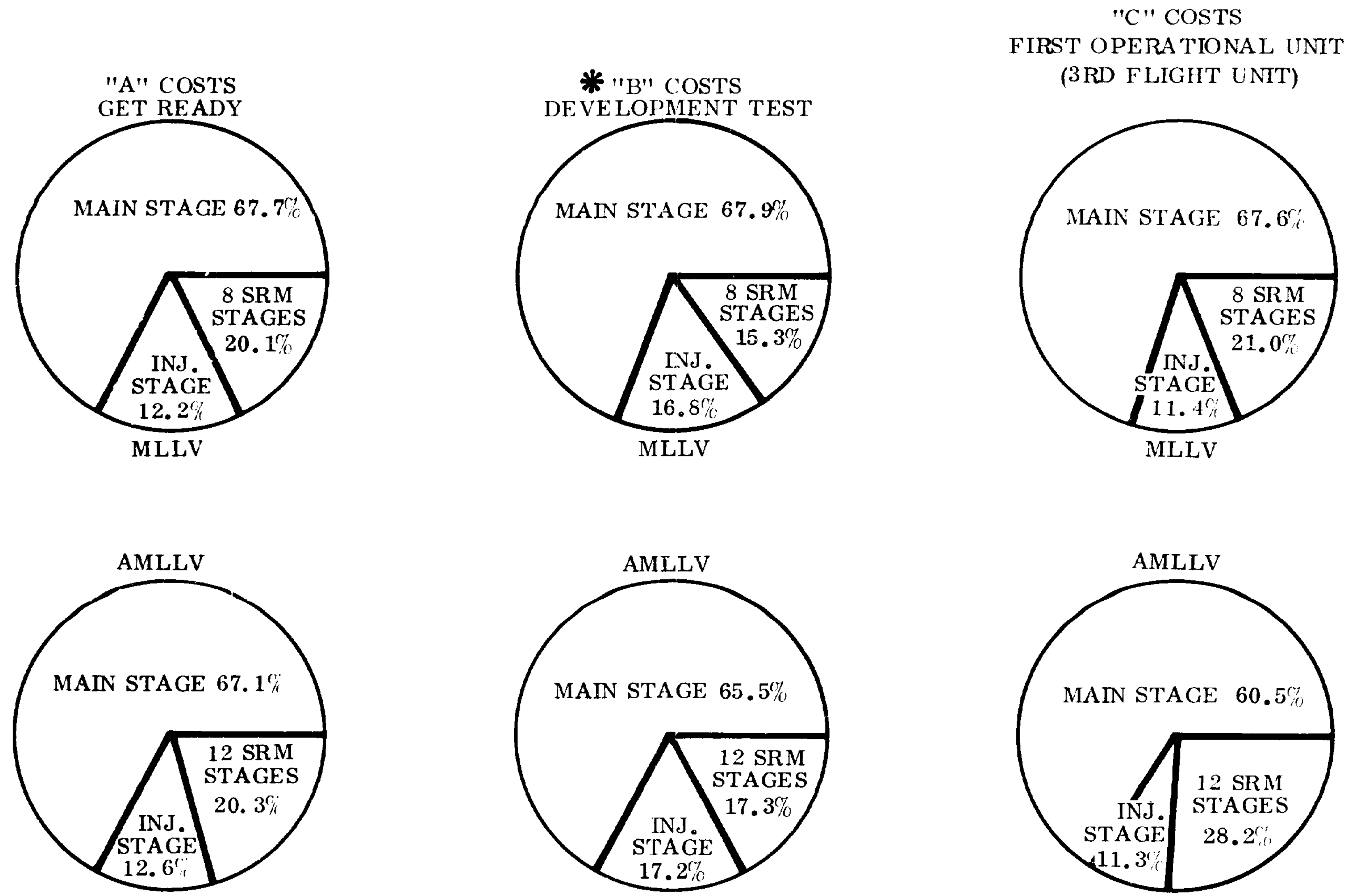


FIGURE 4.1.0.0-1 APPORTIONMENT OF STAGE COSTS BY VEHICLE STAGES AND PROGRAM PHASES



* "B" COSTS INCLUDE TWO R&D FLIGHT TESTS

FIGURE 4.1.0.0-2 STAGE COST DISTRIBUTION BY PROGRAM PHASES FOR THE MAXIMUM SIZE AMLLV AND MLLV CONFIGURATIONS

4.1 (Continued)

	MLLV	AMLLV
$\frac{B}{C \text{ (3rd Flight Unit)}}$	6.66	6.99
$\frac{A + B}{C \text{ (3rd Flight Unit)}}$	11.06	11.51
$\frac{A}{B}$	0.66	0.65

NOTE: (1) Maximum size vehicle refers to a vehicle incorporating a main stage plus a three module injection stage plus a full complement of strap-on stages.

b. Injection Stage (Three Module)	MLLV	AMLLV
$\frac{A}{C \text{ (3rd Flight Unit)}}$	4.68	3.42
$\frac{B}{C \text{ (3rd Flight Unit)}}$	8.92	7.18
$\frac{A + B}{C \text{ (3rd Flight Unit)}}$	13.60	10.60
$\frac{A}{B}$	0.52	0.48

c. Strap-On Stages (Full Complement)	MLLV	AMLLV
$\frac{A}{C \text{ (3rd Flight Unit)}}$	4.22	2.92
$\frac{B}{C \text{ (3rd Flight Unit)}}$	4.83	3.95
$\frac{A + B}{C \text{ (3rd Flight Unit)}}$	9.05	6.87
$\frac{A}{B}$	0.87	0.74

4.1 (Continued)

d. Maximum Size Vehicle

	MLLV	AMLLV
$\frac{A}{C \text{ (3rd Flight Unit)}}$	4.35	4.07
$\frac{B}{C \text{ (3rd Flight Unit)}}$	6.63	6.44
$\frac{A + B}{C \text{ (3rd Flight Unit)}}$	10.98	10.51
$\frac{A}{B}$	0.66	0.63

B costs used for the above ratios include the costs of two R&D flight tests of a vehicle incorporating a main stage plus a three module injection stage plus the maximum complement of strap-on stages. The cost data presented in Figure 4.1.0.0-3 shows that the costs of the two R&D flight tests represent approximately one-fourth of the non-recurring costs for either the MLLV or AMLLV vehicle families.

If useful payloads could be flown on these R&D flight test vehicles, the non-recurring costs would, therefore, be reduced by a factor of 25%. This overall savings would not, however, be realized within the total program costs as the costs of the first two flight units would increase by approximately 10% to account for position on the learning curve, the additional time for the initial launch cycles and the additional instrumentation requirements.

Figure 4.1.0.0-4 shows the stage costs for phase A distributed by the major program elements. These costs are modularized and presented in such a manner that they can be added. The solid rocket motor strap-on stage "A" costs are for the maximum vehicle configurations, i.e., eight MLLV and twelve AMLLV strap-on stages. "A" costs for the injection stage fuel modules are for design effort only, as the facilities provided for the engine module of the injection stage will be adequate for production and operation of the fuel modules.

The "B" costs for the various vehicle stages are displayed in Figure 4.1.0.0-5. These costs are distributed by costs attributable to each of the major development tests.

The basic approach used in compiling the non-recurring cost data shown in Figures 4.1.0.0-6 through 4.1.0.0-9 assumed that all launches will be made using only one of the several possible MLLV configurations shown. All included costs relate to facilities, equipment and tooling sized for production and launch of only the configuration being used. The two R&D flight test vehicles are of the specific operational vehicle to be flown.

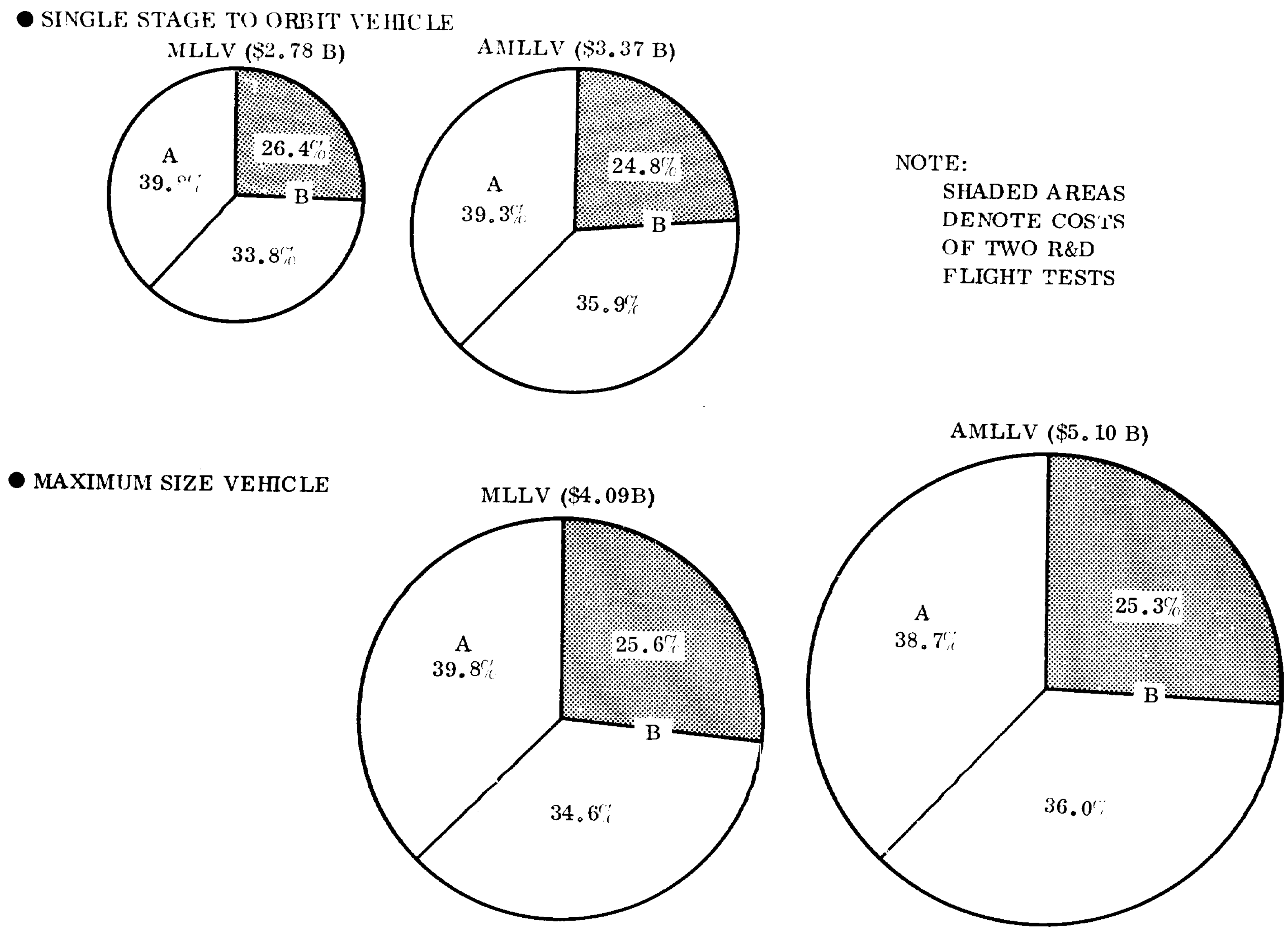


FIGURE 4.1.0.0-3 FLIGHT TEST COSTS RELATIVE TO NON-RECURRING COSTS

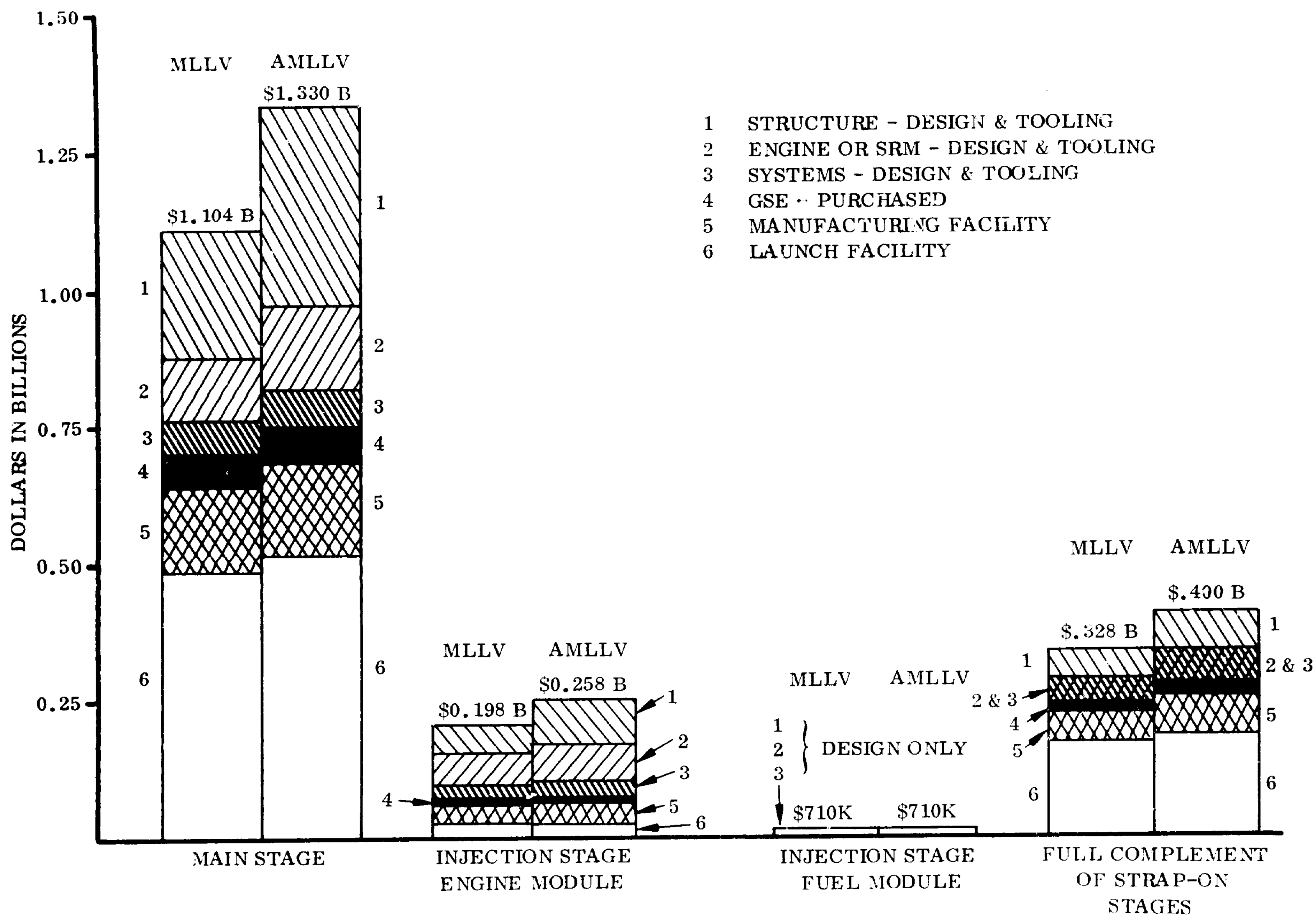


FIGURE 4 1.0.0-4 STAGE ELEMENT COST DISTRIBUTION FOR PHASE A

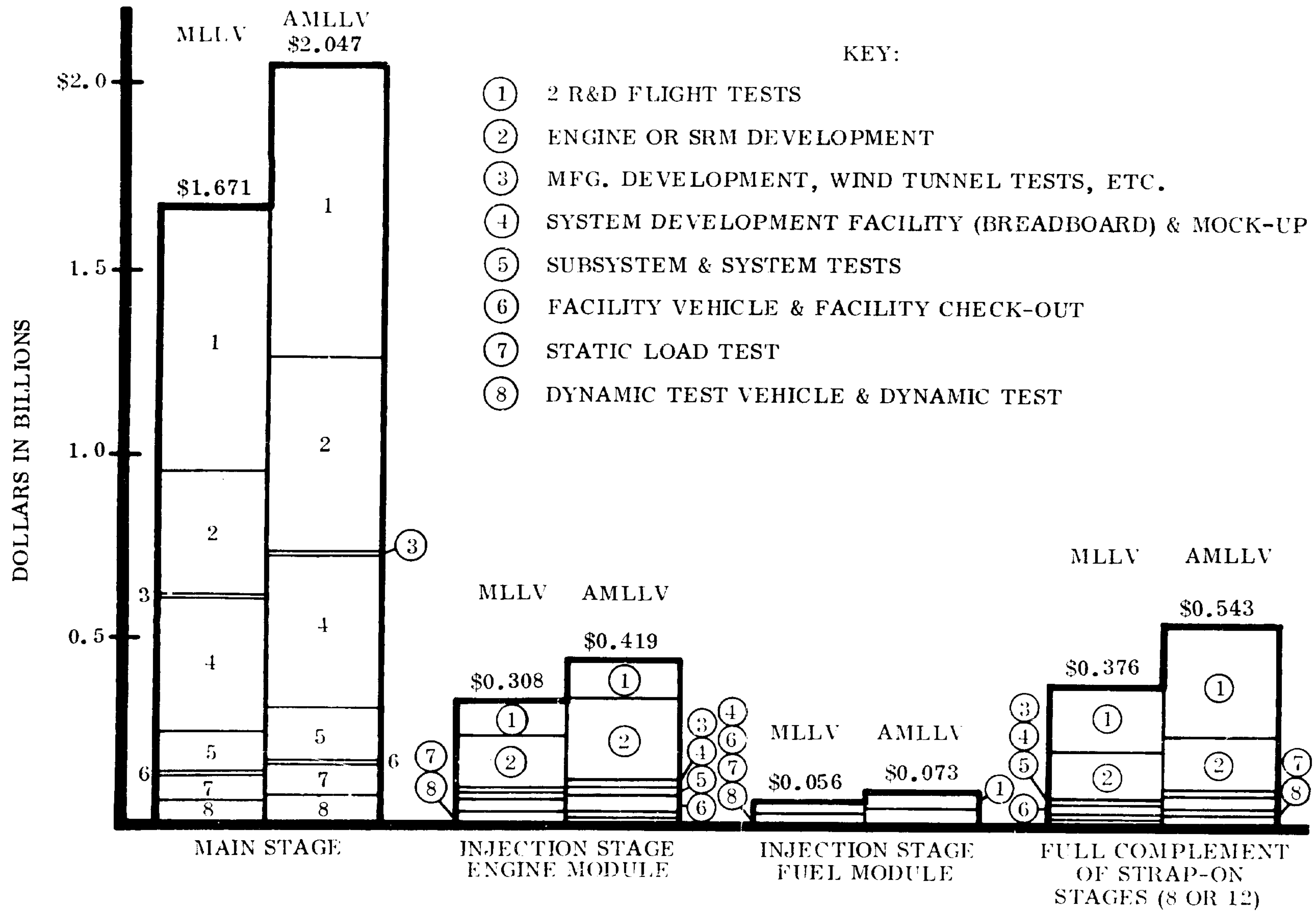


FIGURE 4.1.0.0-5 STAGE ELEMENT COST DISTRIBUTION FOR PHASE B

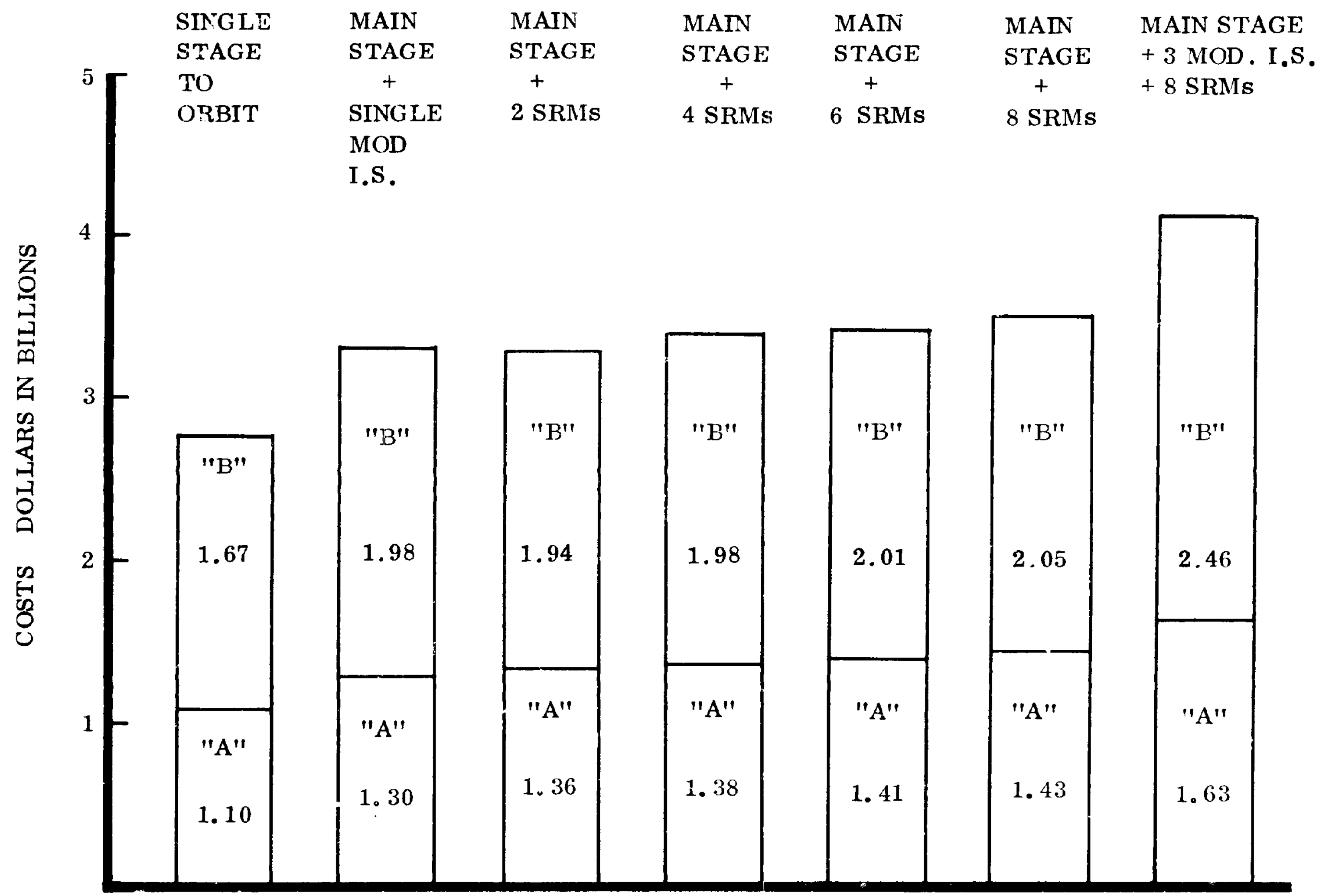


FIGURE 4.1.0.0-6 MLLV NON-RECURRING COST SUMMARY

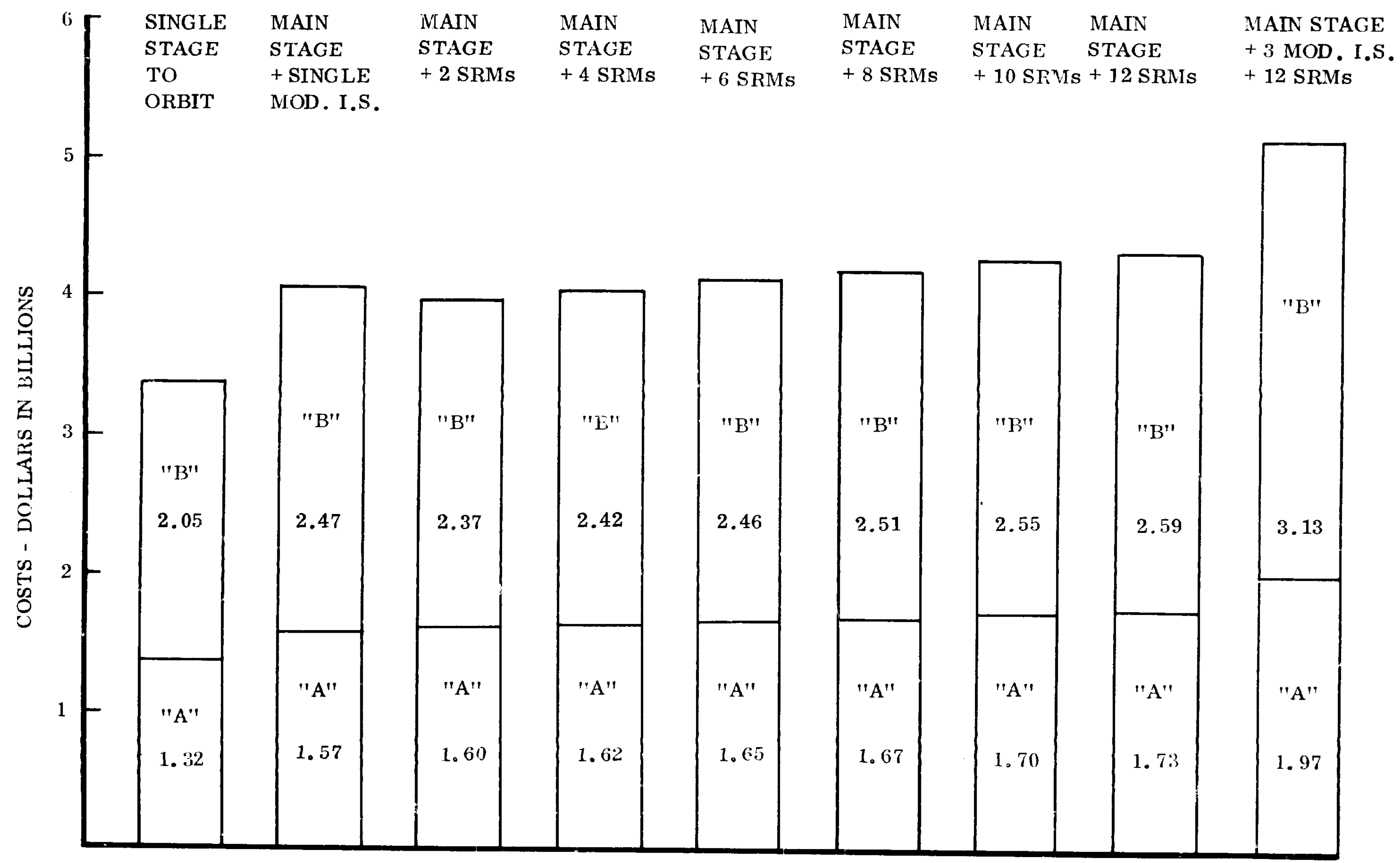


FIGURE 4.1.0.0-7 AMLLV NON-RECURRING COST SUMMARY

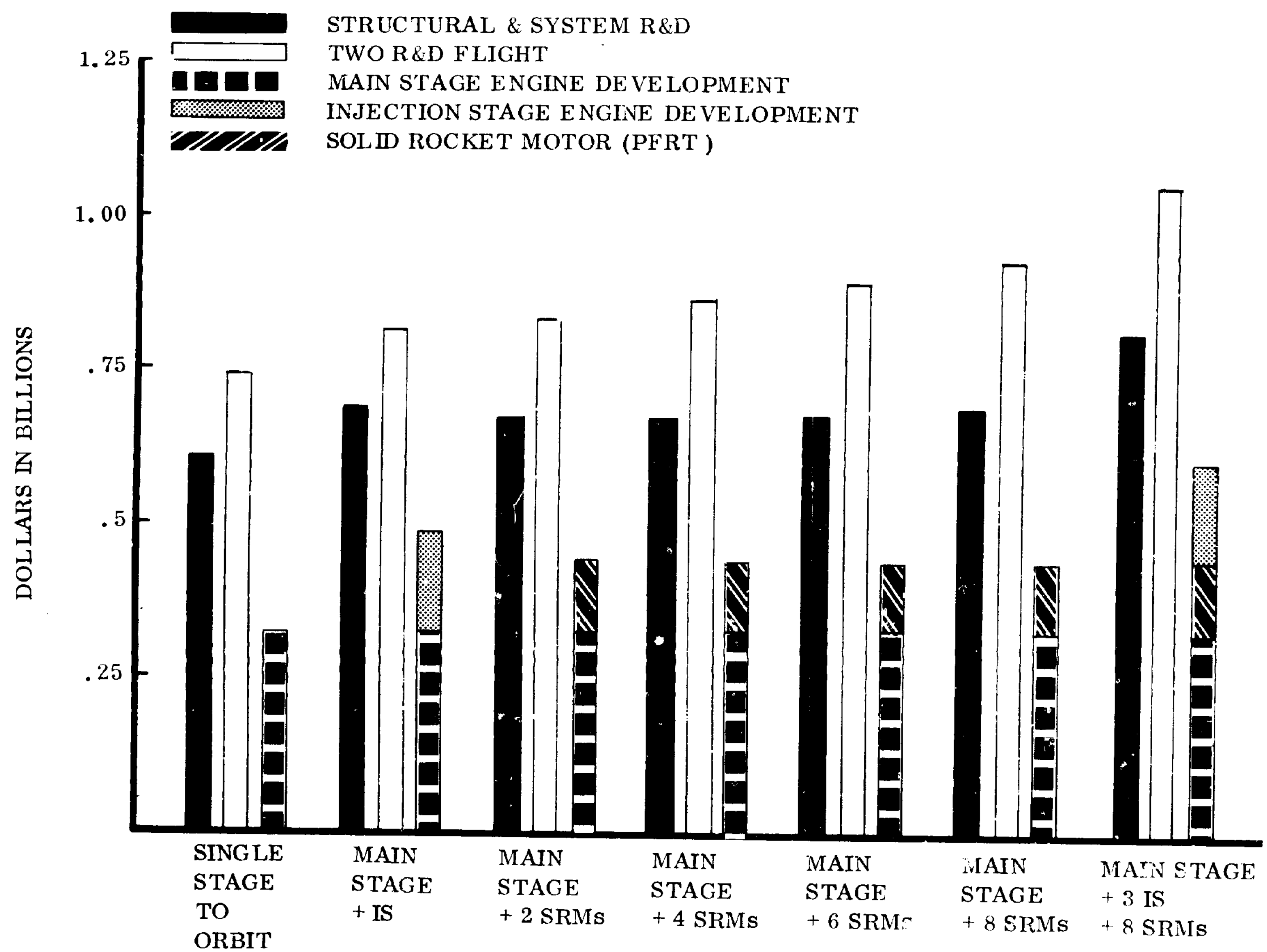


FIGURE 4.1.0.0-8 MLLV - "B" R&D TEST COST SUMMARY

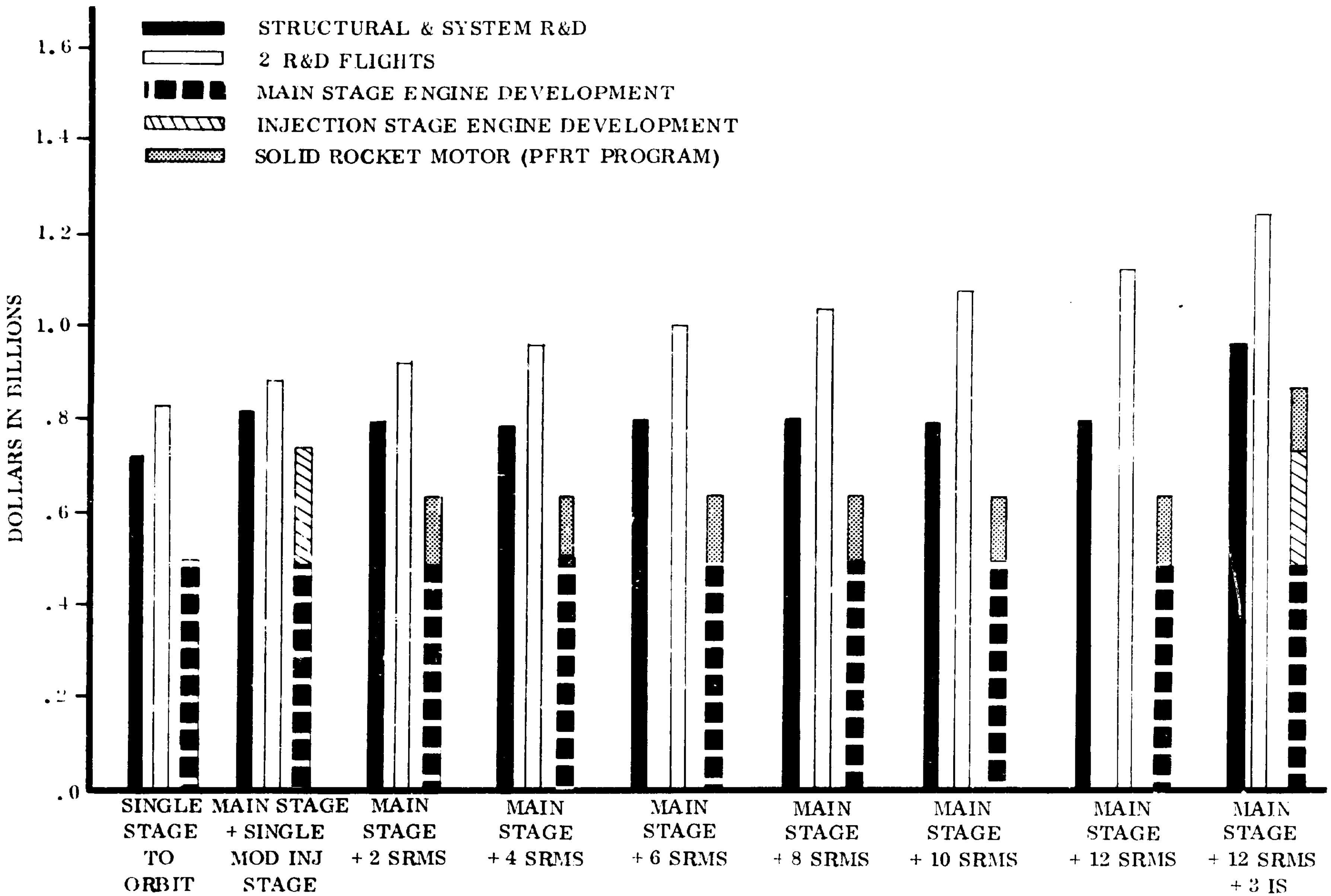


FIGURE 4.1.0.0-9 AMLLV "B" R&D TEST COST SUMMARY

4.1 (Continued)

These figures show that the non-recurring cost for implementation of the injection stage are basically the same as for the solid rocket motor stages. They further show that the non-recurring costs will be relatively insensitive to the number of injection stage modules and/or the number of SRM stages to be used for the vehicle configurations.

The costs for flight test portion of the development test program will exceed the development test costs for either structures and systems or the propulsion systems. The flight test costs are approximately 40 to 50 percent higher than the test costs for structures and systems development and 100 to 160 percent higher than the costs for propulsion system development. The development test costs for the structures and systems exceeds the development test costs for the propulsion systems by approximately 50 percent for the single-stage-to-orbit configuration and by 30 to 50 percent for the other configuration.

Another approach (not shown) would assume that all program support elements will be sized for the maximum configuration and that all other configurations can be produced and launched for various mixes of launch vehicle within a program. The two R&D flight vehicles are of the maximum payload configuration.

For this approach which would assume that capability for launching the maximum configuration must be maintained, the "A" and "B" costs will be constant for all configurations and the same as those shown for the maximum configuration in the aforementioned figures.

"C" costs by program element for the first units of both vehicle families are shown in Figure 4.1.0.0-10. (To use these data in development of a total program cost, that requires multiple launches, appropriate learning curves must be used for obtaining the overall program operational costs.)

The above referenced figures also show the relationship of the cost distributions to vehicle size. From these data the following cost/size/phase relationships were determined.

	Phases		
	A	B	C
MLLV Main Stage / AMLLV Main Stage	.832	.817	.855
MLLV Injection Stage Engine Module / AMLLV Injection Stage Engine Module	.799	.737	.799
MLLV Injection Stage Fuel Module / AMLLV Injection Stage Fuel Module	1.000	.772	.742

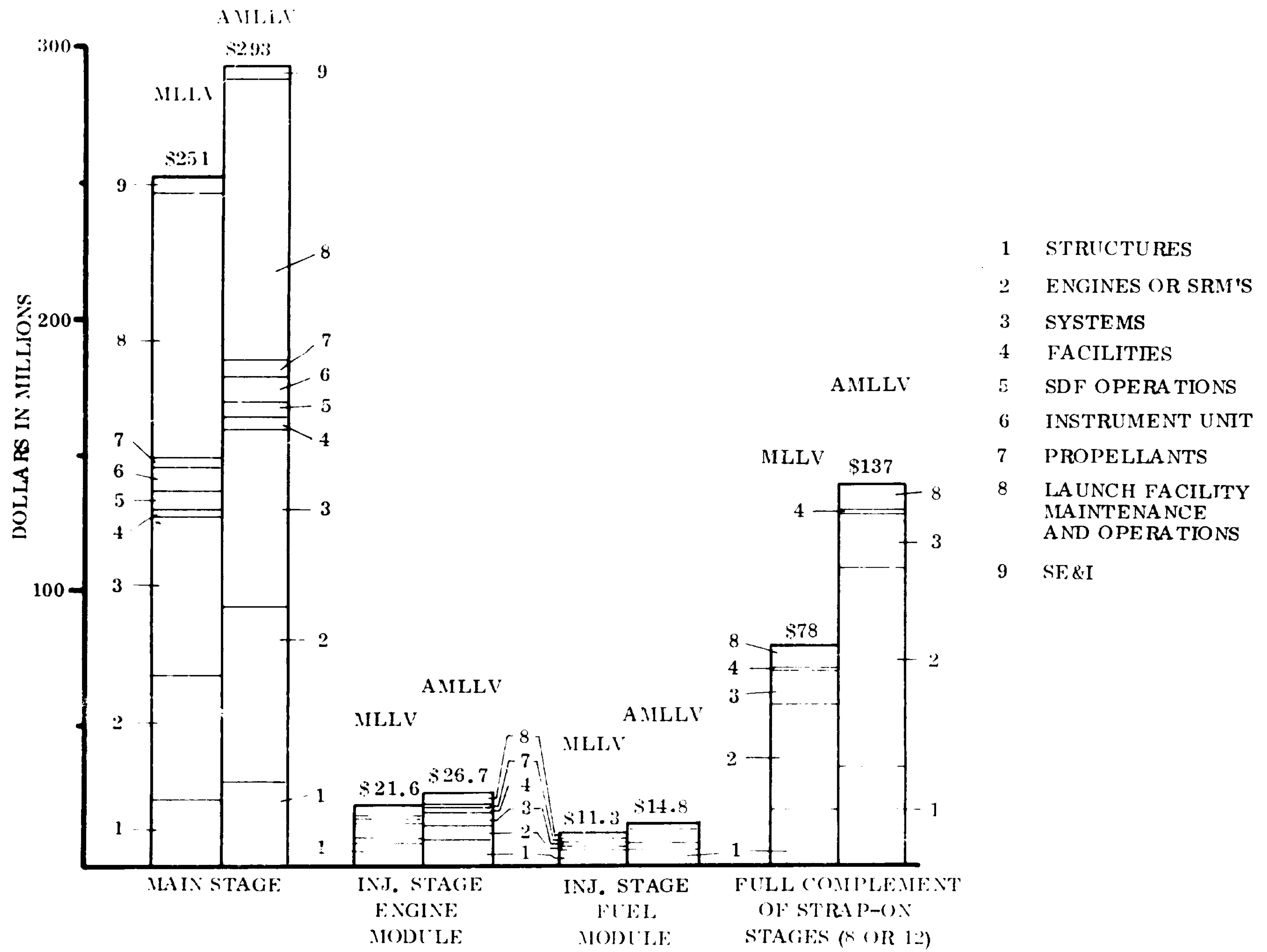


FIGURE 4.1.0.0-10 STAGE ELEMENT COST DISTRIBUTION FOR FIRST OPERATIONAL UNIT (3RD FLIGHT UNIT) "C" COST

4.1 (Continued)

	PHASES		
	A	B	C
MLLV Three Module Injection Stage / AMLLV Three Module Injection Stage	.799	.730	.779
MLLV Strap-On Stage / AMLLV Strap-On Stage	.868	.693	.844
MLLV Full Complement of Strap-on Stages / AMLLV Full Complement of Strap-on Stages	.817	.692	.565

NOTE: All of the above relationships relate to a 50% size reduction except for that of the individual strap-on stage which relates to a 23% size reduction.

As these numbers indicate, a 50 percent reduction in the main stage size will result in only a 15 percent reduction in the main stage recurring costs while a 50 percent reduction in the injection stage size will result in approximately a 20 percent reduction in injection stage recurring cost and a 23 percent size reduction for an individual strap-on stage will result in a 16 percent reduction in cost (a 55% cost reduction for a 50 percent size reduction). The basis for this anomaly (as stated above) is that the main stage, as a primary vehicle stage, must absorb a significant portion of the fixed non-size sensitive cost associated with facility, maintenance and operations. The cost of the full complement of strap-on stages for the half size vehicle will be only 60 percent that for the full size vehicle. This significant reduction in strap-on stage costs is due to the combination of: (1) the effects of size reduction of the individual stages and (2) the reduction in number of required strap-on stages from 12 to 8.

Figure 4.1.0.0-11 through 4.1.0.0-13 show the distribution of costs by cost categories by stage by program phase. The distribution of costs to the cost categories was accomplished by reviewing each individual entry in the back-up detailed cost sheets in the AMLLV and MLLV baseline costs contained in Volumes IV and V, respectively. Assignment of a specific cost entry to a given cost category was based on an individual judgement of each entry. Some of these assignments required arbitrary assumptions which would effect the total distributions shown. For example, manpower and vehicle material as shown, relate only to that manpower and vehicle material to be expended to design, test, build and operate the vehicle. Manpower required in support of the other categories, i.e., tooling, material, facilities and equipment is included in the cost of those items as applicable. For example, manpower for tool design is shown as a tooling cost. Similarly, material required for tooling is shown as a tooling cost. Material costs as assigned to the vehicle material category reflect all costs for purchases material (inclusive of purchased assemblies and subsystems) to be used to design, test, manufacture and operate the vehicle. SRM and liquid engines for this distribution were not considered purchased

4.1 (Continued)

assemblies (vehicle material) but were further broken down into the manpower, material, tooling, fabrication and equipment by categories. All systems and subsystems, on the other hand, were classified as vehicle material exclusively.

The distribution of Phase A costs by cost category as shown in Figure 4.1.0.0-11, indicates that a significant portion of the "Get Ready" costs will be attributable to Facilities and Equipment. The next largest cost category will be tooling. Of the cost categories shown, the tooling costs appear to be the most sensitive to vehicle size. Tooling costs will be reduced by 28 percent as the vehicle size is reduced by 50 percent while the total A costs will be reduced by only approximately 17% for a similar size reduction. The costs for vehicle material will be negligible. Program management and engineering design costs will represent approximately only 1.2 percent and 5.0 percent respectively of the total Phase A costs.

The ratio of MLLV costs to AMLLV costs for the main stage, for the three module injection stage, and the full complement of strap-on stages will vary between 80 and 83.5 percent. This is indicative of the fact that the major cost elements are relatively independent of size. Only a slight difference in the costs for equipment and the facilities, tooling, and material will occur between the MLLV and the AMLLV sizes. The manpower requirements will be essentially the same regardless of the size.

Figure 4.1.0.0-12 illustrates the distribution of costs by categories for Phase B. These costs include not only the costs for conducting the test, but also the costs required to provide the test specimens. The development test costs for the MLLV single-stage-to-orbit will be 81.5 percent those of the AMLLV. Similar comparisons of the development test costs of the MLLV and AMLLV three module injection stages and full complements of strap-on stages showed the ratios will be 74.1 and 69.2 percent, respectively. For all stages of the vehicle, the tooling and facilities equipment costs will be essentially identical regardless of the size. A relatively significant increase will occur for material costs for the larger vehicle. The major difference in MLLV and AMLLV SRM stage costs can be attributed almost entirely to the increased propellant that will be required in each test SRM. The manpower costs which represent the major portion (70%) of the liquid stage B costs will increase only slightly as the size goes up. This is the effect of increased manpower requirements for manufacturing operations, test and quality and reliability assurance. As most of the SRM stage test components will be purchased, material costs for the SRM exceed the manpower costs. The management and administration and the vehicle engineering are essentially the same.

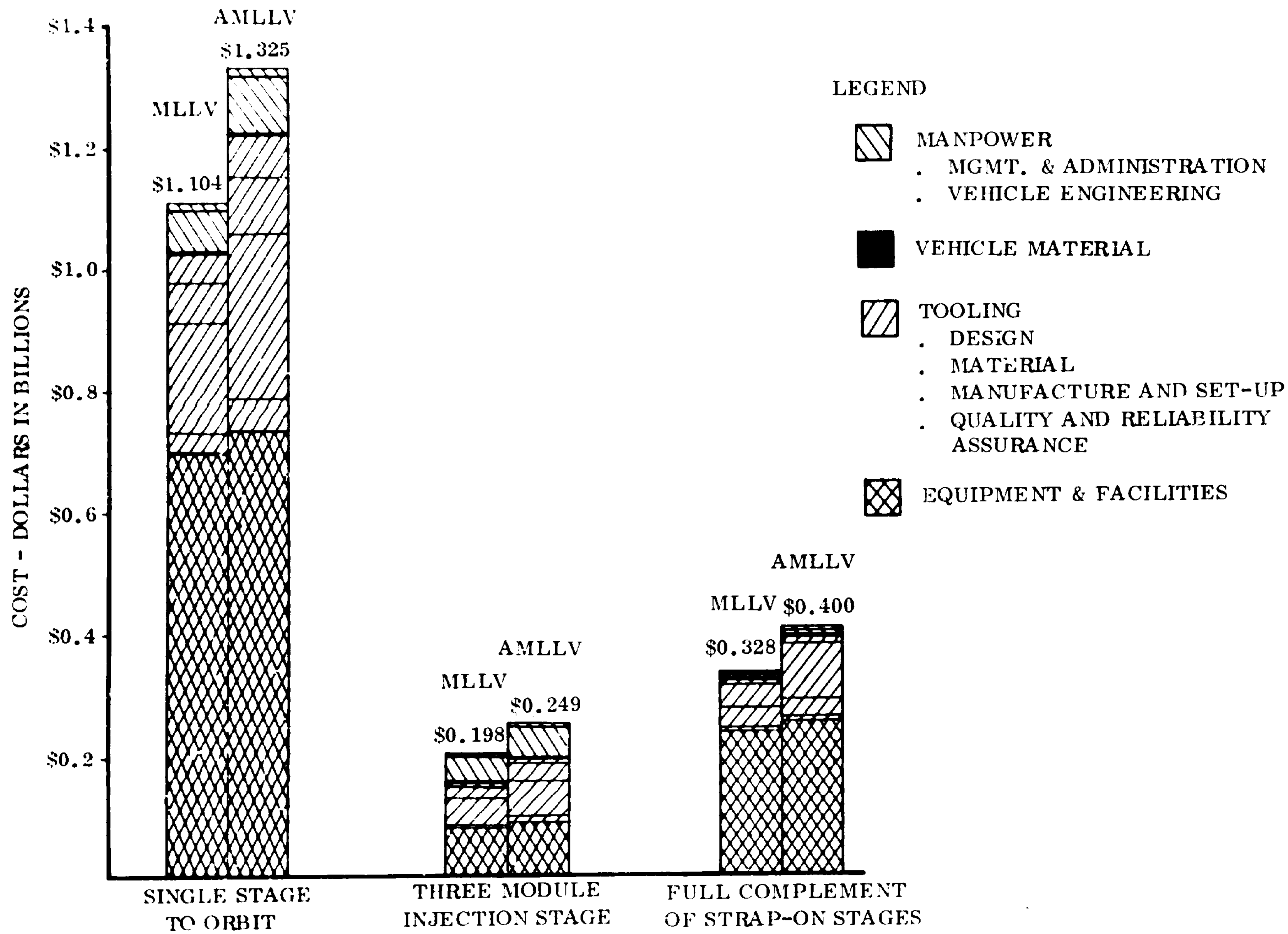


FIGURE 4.1.0.0-11 DISTRIBUTION OF COST BY COST CATEGORY FOR PHASE A

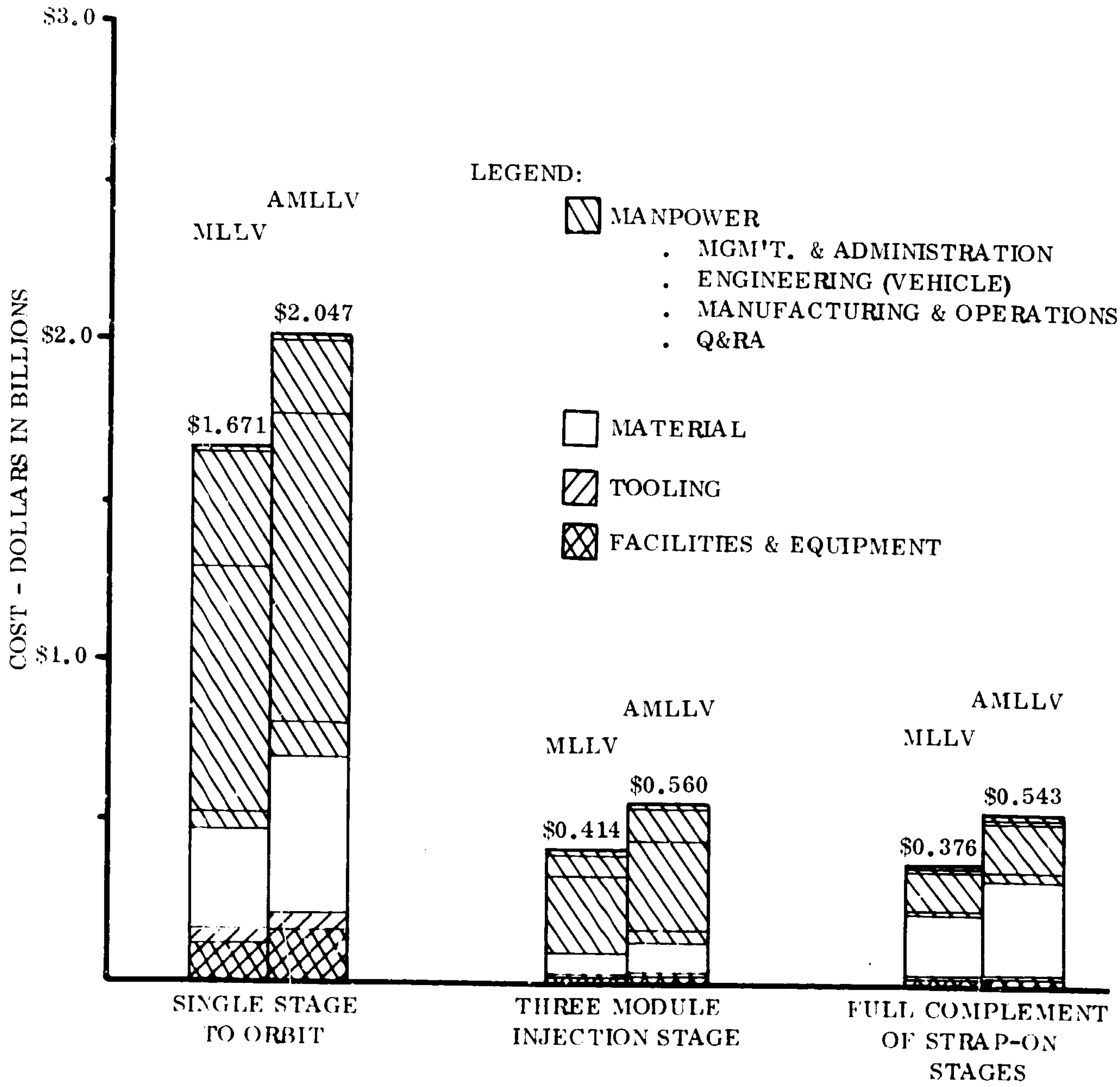


FIGURE 4.1.0.0-12 DISTRIBUTION OF COSTS BY CATEGORY FOR PHASE B

4.1 (Continued)

Figure 4.1.0.0-13 shows the distribution of costs by category for the first operational unit (C cost). The costs of the MLLV stages as ratioed to those of the AMLLV stages will be 86.5 percent, 77.8 percent, and 87.2 percent for the single-stage-to-orbit (main stage), three module injection stage, and full complement of strap-on stages, respectively. As was observed for the costs for Phase B, the facility, tooling and equipment will be essentially the same regardless of size. The material costs will be relatively higher for the AMLLV single-stage-to-orbit vehicles and for the AMLLV full complement of strap-on stages. For the single-stage-to-orbit vehicle, this will be a direct effect of the size increase. For the strap-on stages, it will be principally due to the twelve SRM's for the AMLLV versus the 8 SRM's for the MLLV as well as the increased propellant loading for the AMLLV SRM's of approximately 1,000,000 pounds each. The material costs for the three module injection stage will not be significantly affected by size. The costs for manpower will represent by far the majority of the liquid stage production and launch costs. Manpower costs will be a smaller percentage of SRM stage costs because of the high percentage of purchased propellant materials and stage components. The differences in costs for manpower between each of the MLLV and AMLLV stages will be principally due to the manufacturing and operations test and quality and reliability assurance. The management and administration and vehicle engineering manpower will be essentially the same regardless of vehicle size.

Figure 4.1.0.0-14 and 15 illustrate the AMLLV and MLLV main stage production and launch cost distributions compared to the Saturn V cost distributions. Figure 4.1.0.0-14 shows that the main stage manufacturing cost distributions by cost categories of the AMLLV and the MLLV will be similarly comparable to those of the S-IC stage of the Saturn V.

As shown in Figure 4.1.0.0-15, the costs distributions by cost elements will be generally comparable except for the engine cost. For the MLLV and AMLLV, the engine costs will be a significantly larger percentage of vehicle costs than will the engine costs for the Saturn V. This can be attributed principally to the number of engines involved. For the MLLV and the AMLLV twenty-four engines will be used per main stage whereas, for the two stage Saturn V a total of ten engines are utilized.

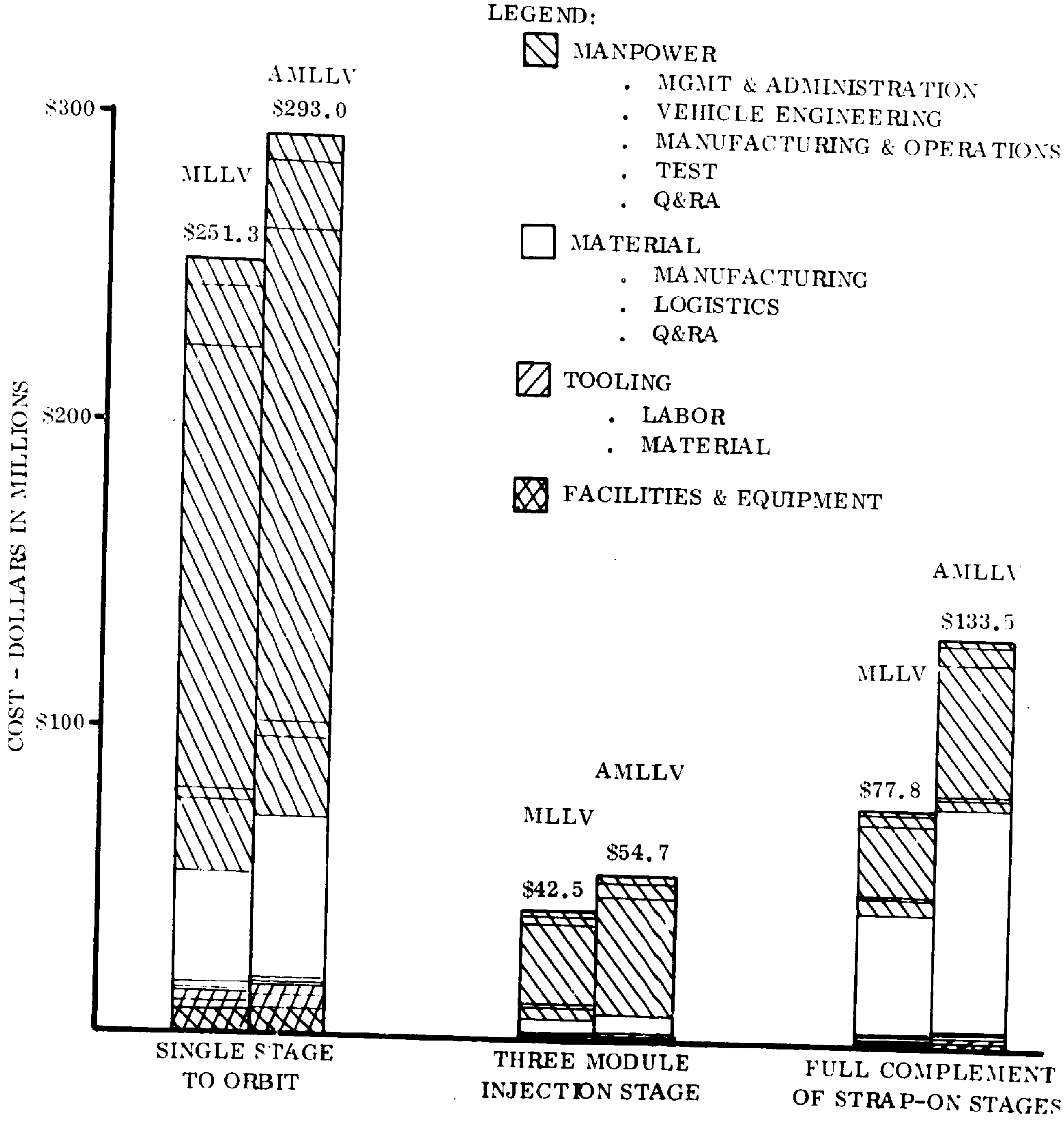


FIGURE 4.1.0.0-13 DISTRIBUTION OF COSTS BY CATEGORY FOR FIRST OPERATIONAL UNIT (3RD FLIGHT UNIT)

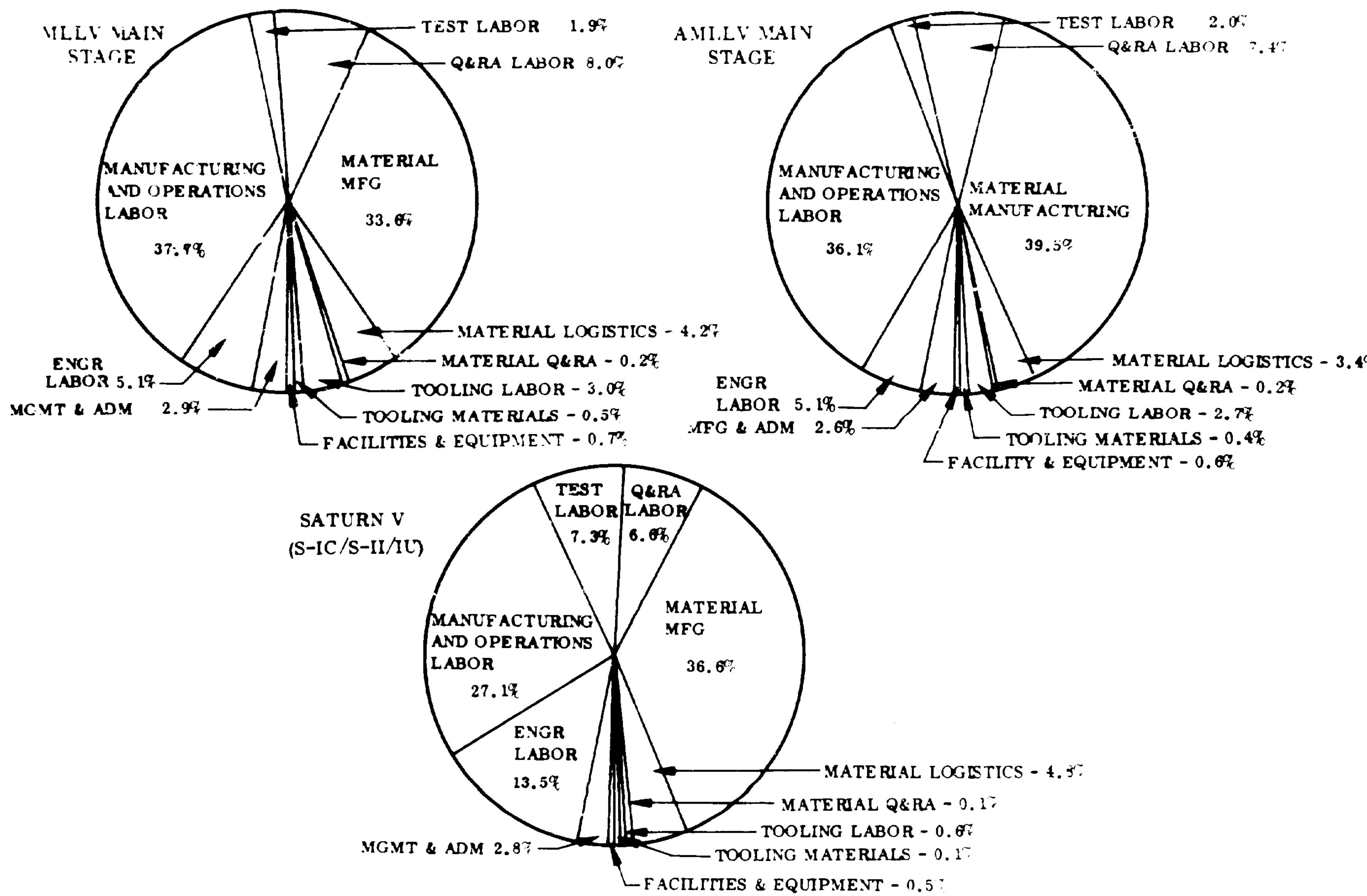


FIGURE 4.1.0.0-14 AMLLV AND MLLV MAIN STAGE PRODUCTION COSTS ("C" COSTS) COST CATEGORIES COMPARED TO SATURN V VEHICLE COST CATEGORY

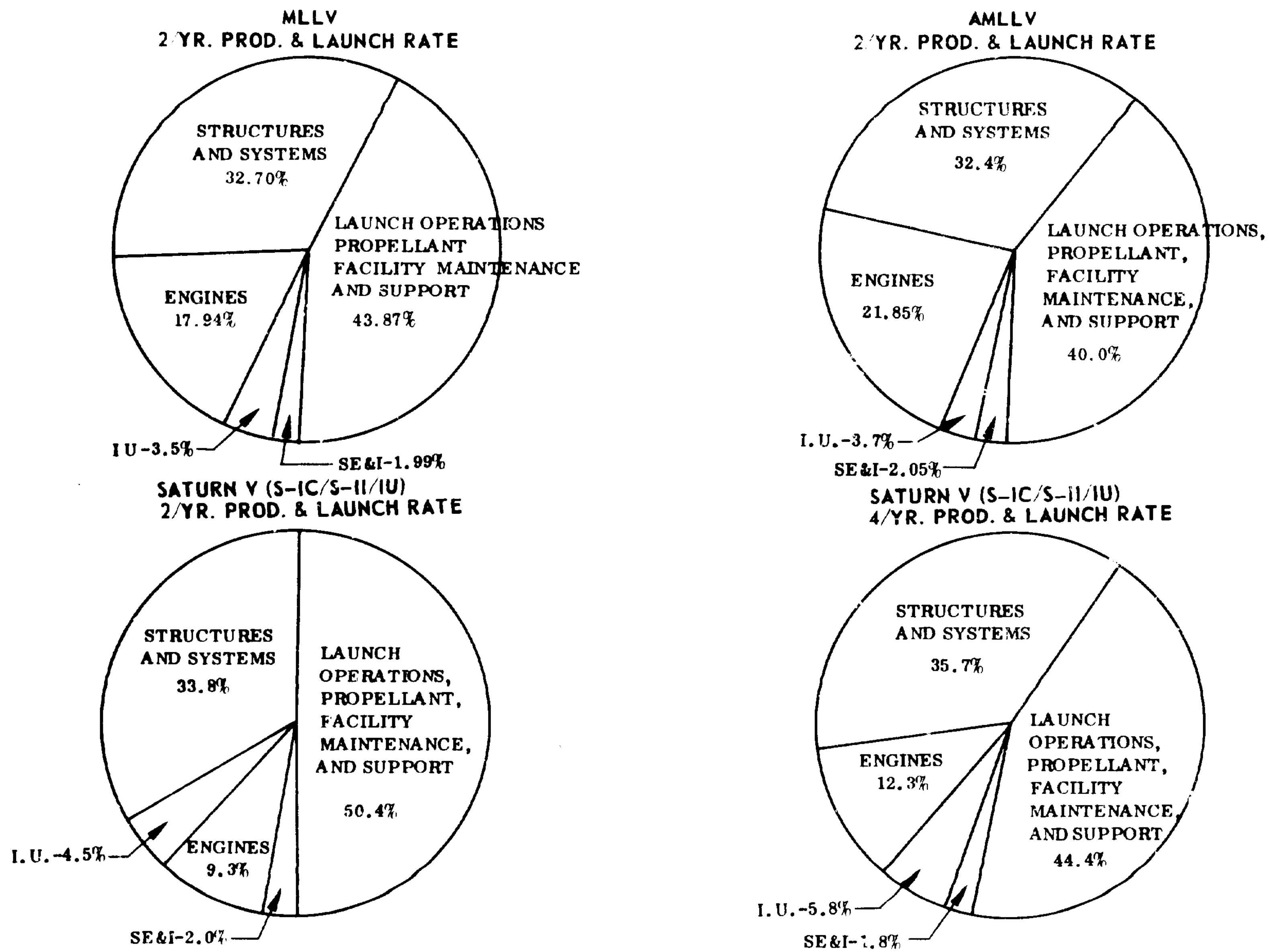


FIGURE 4.1.0.0-15 AMLLV AND MLLV MAIN STAGE PRODUCTION AND LAUNCH COSTS ("C" COSTS) COST ELEMENTS COMPARED TO SATURN V COST ELEMENTS

4.2 LEARNING CURVE EFFECTS ON RECURRING COSTS FOR PRODUCTION AND LAUNCH

The preceding data show only recurring costs for the first flight stages. To evaluate overall program costs, (as required for cost effectiveness analyses of program, configuration and technology alternatives) it is necessary that recurring cost be computed for varying production quantities of the individual stages. To accomplish these computations, learning curve effects on the cost of the various stages and stage elements must be applied. For the purpose of applying the learning curve data, the first stage produced for flight (the first R&D flight test) was considered as the number one unit.

The first unit costs and learning curve values shown on Table 4.2.0.0-I were defined for the various stage and stage elements. (See Book C of Volumes IV or V.)

As shown in Table 4.2.0.0-I, two learning curve rates were utilized in determining the cost of the variable cost AMLLV/MLLV components. These learning rates were: 1) 91% for the main stage structure, injection stage engine module, injection stage fuel module, and delta cost for the heavy weight alternate forward skirt and 2) 95% for the main stage engine, injection stage engine and solid propellant motors.

For reference, improvement curve (learning rate) tables are provided in Tables 4.2.0.0-II through 4.2.0.0-V. Tables 4.2.0.0-II and 4.2.0.0-III show the unit progressive curves for the 91% and 95% learning curves, respectively. Tables 4.2.0.0-IV and 4.2.0.0-V show the cumulative progressive curves for 91% and 95% learning curves, respectively. An application of each type of these curves are shown below.

Unit Progressive Curve Application - The first unit cost of the AMLLV main stage learning curve sensitive elements (exclusive of engines) are 118 million dollars. To determine the costs of these elements for the sixth unit, the 91% unit progressive curve tables are used. The first unit costs of 118 million dollars are multiplied by the factor .78365300. This product is equal to 92.47 million dollars. If the costs of the sixth unit are known, i.e., 92.47 million dollars, the costs of the first unit may be obtained by dividing the sixth unit factor from the unit progressive curve table, i.e., 92.47 divided by .78365300 equals 118 million dollars.

Cumulative Progressive Curve Application - If it is desired to obtain the cumulative costs of the first six units, the cumulative progressive tables must be utilized. For example: the first unit costs of the AMLLV SRM stage learning curve sensitive elements are 13.05 million dollars. The SRM stage learning curve sensitive elements costs are on a 95% learning curve. If it is desired to determine the cumulative costs of these elements for the first six units, the first unit costs of 13.05 million dollars are multiplied by the cumulative progressive table factor for the sixth unit, 5.537962. The product is equal to 72.27 million dollars. If the total costs of the six units are

TABLE 4.2.0.0-I LEARNING CURVE AND ASSOCIATED COSTS FOR AMLLV/MLLV ELEMENTS

PROGRAM ELEMENTS	AMLLV 1ST R&D FLIGHT	AMLLV 1st OPERATIONAL FLIGHT	MLLV 1st R&D FLIGHT	MLLV 1st OPERATIONAL FLIGHT	LEARNING CURVE
	(DOLLARS IN THOUSANDS)				
MAIN STAGE - VARIABLE COSTS	(118,000)	(101,616)	(95,000)	(81,810)	
Structures	34,383	29,609	23,464	20,206	91% Composite
Systems	77,884	67,070	67,115	57,797	
Facility and Transportation	4,380	3,772	3,972	3,421	
Engine Installation	865	745	865	745	
MAIN STAGE - FIXED COSTS	(238,500)	(130,000)	(226,000)	(125,000)	
Propellant	6,573	6,573	3,287	3,287	100%
Instrument Unit	9,346	9,346	9,346	9,346	
SDF Operations	6,169	6,169	6,169	6,169	
Operational Vehicle Launch Operations	-	94,164	-	88,506	
Launch Maintenance	8,750	8,750	8,750	8,750	
SE&I	5,301	5,301	5,301	5,301	
R&D Launch Operations Delta SE&I, Inst.	202,361	-	193,147	-	
MAIN STAGE - ENGINE COSTS					
Multichamber/Plug	(71,100)	(66,065)	(50,800)	(47,203)	
Toroidal/Aerospike					ENGINE ALTERNATIVES 95%
286K-1200 psi	-	-	(32,800)	(30,477)	
1M-1200 psi	-	-	(32,200)	(21,557)	
1M-2000 psi	(65,900)	(61,234)	(23,500)	(21,836)	
2M-2000 psi	(76,000)	(70,618)			

TABLE 4.2.0.0-I LEARNING CURVE AND ASSOCIATED COSTS FOR AMLLV/MLLV ELEMENTS (Continued)

(DOLLARS IN THOUSANDS)

PROGRAM ELEMENTS	AMLLV 1st R&D FLIGHT	AMLLV 1st OPERATIONAL FLIGHT	MLLV 1st R&D FLIGHT	MLLV 1st OPERATIONAL FLIGHT	LEARNING CURVE
ENGINE MODULE - VARIABLE COSTS	(20,400)	(17,826)	(16,700)	(14,381)	
Structures	11,073	9,536	7,881	6,787	91%
Systems	7,873	6,780	7,485	6,446	
Facility and Transp.	1,396	1,202	1,310	1,128	
Engine Installation	68	59	68	59	
ENGINE MODULE - ENGINE COSTS	(3,800)	(3,530)	(2,700)	(2,509)	95%
ENGINE MODULE - FIXED COSTS	(17,400)	(5,800)	(16,600)	(4,700)	
Propellant	730	730	365	365	
Operational Vehicle Launch Operations	-	5,044	-	4,311	100%
R&D Launch Operations Delta SE&I, Inst.	16,670	-	16,238	-	
FUEL MODULE - VARIABLE COSTS	(9,600)	(8,267)	(7,100)	(6,114)	
Structures	7,000	6,028	4,618	3,977	91% Composite
Systems	2,575	2,217	2,411	2,076	
Engine Installation	67	58	67	58	
FUEL MODULE - ENGINE COSTS	(3,600)	(3,345)	(2,500)	(2,323)	95%
FUEL MODULE - FIXED COSTS	(6,000)	(3,300)	(4,900)	(2,700)	
Propellant	730	730	365	365	
Operational Vehicle Launch Operations	-	3,523	-	2,374	100%
R&D Launch Operations Delta SE&I, Inst.	5,270	-	4,535	-	

TABLE 4.2.0.0-I LEARNING CURVE AND ASSOCIATED COSTS FOR AMLLV/MLLV ELEMENTS (Continued)

(DOLLARS IN THOUSANDS)

PROGRAM ELEMENT	AMLLV 1st R&D FLIGHT	AMLLV 1st OPERATIONAL FLIGHT	MLLV 1st R&D FLIGHT	MLLV 1st OPERATIONAL FLIGHT	LEARNING CURVE
ALTERNATE FWD SKIRT COSTS	(4,600)	(3,961)	(2,900)	(2,497)	91%
SRM STAGE - FIXED COSTS	(27,400)	(7,900)	(20,600)	(6,500)	100%
Launch Maintenance	1,150	1,150	1,150	1,150	
Operational Vehicle Launch Operations	–	6,725	–	5,305	
R&D Launch Operations Delta SE&I, Inst.	26,250	–	18,450	–	
SRM STAGE - VARIABLE COSTS	(136,663)*	(128,844)*	(78,087)**	(72,558)**	95% Composite
Structures	38,183	35,479	21,218	19,716	
SRM Motors	82,070	76,257	94,308	87,623	
Facility Maintenance	1,104	1,026	733	681	
Other Stage Hardware	17,306	16,081	11,828	10,990	
	*Block of 12 SRM's	*Block of 12 SRM's	**Block of 8 SRM's	**Block of 8 SRM's	

4.2 (Continued)

known, i.e., 72.27 million dollars, that number divided by the above factor (5.537962) will give the first unit costs of 13.05 million dollars.

To aid in application of the learning curve effects to the cost analyses, the MLLV data was tabulated as shown in Tables 4.2.0.0-VI through 4.2.0.0-XII. Similar data for the AMLLV is shown in Tables 4.2.0.0-XIII through 4.2.0.0-XVIII. (NOTE: These cost data apply only to a production and launch rate of two per year.)

Examples showing the use of these tables are provided in the following Section 4.3.

TABLE 4.2.0.0-II 91% UNIT PROGRESSIVE CURVE TABLE

UNIT PROGRESS CURVE TABLE 91%

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.91000000	.86115700	.82810000	.80335600	.78365300	.76738700	.75357100	.74159100
1	.73103500	.72161700	.71312400	.70539900	.69832300	.69179000	.68575000	.68011600	.67484400	.66990000
2	.66524200	.66084100	.65667100	.65271100	.64894300	.64534800	.64191400	.63862600	.63547300	.63244700
3	.62953600	.62673600	.62403200	.62142500	.61890400	.61647000	.61411100	.61182600	.60961000	.60746900
4	.60537000	.60334000	.60136500	.59944300	.59757100	.59574600	.59396700	.59223200	.59053800	.58888300
5	.58726700	.58568700	.58414100	.58262900	.58114900	.57970000	.57828100	.57689000	.57552600	.57418900
6	.57287800	.57159100	.57032800	.56908700	.56786900	.56667300	.56549700	.56434100	.56320400	.56208700
7	.56098700	.55990600	.55884100	.55779300	.55676200	.55574600	.55474500	.55375900	.55278800	.55183100
8	.55088700	.54995700	.54903300	.54813500	.54724200	.54648200	.54560300	.54468600	.54378900	.54294000
9	.54212900	.54131500	.54051000	.53971600	.53893100	.53815600	.53738000	.53663200	.53588400	.53515400
10	.53441300	.53369000	.53297500	.53226800	.53156900	.53087700	.53019300	.52951600	.52884800	.52818100
11	.52752700	.52687800	.52623600	.52560000	.52497000	.52434800	.52372000	.52311800	.52251200	.52191300
12	.52131900	.52073000	.52014800	.51957000	.51899800	.51843100	.51786900	.51731300	.51676100	.51621400
13	.51567200	.51513500	.51460200	.51407400	.51355000	.51303100	.51251600	.51200500	.51149900	.51099700
14	.51049900	.51000400	.50951400	.50902800	.50854600	.50806700	.50758200	.50712100	.50665300	.50618900
15	.50572900	.50527200	.50481800	.50436800	.50392100	.50347800	.50303700	.50260000	.50216600	.50173500
16	.50130700	.50088200	.50046100	.50004200	.49962600	.49921300	.49880300	.49839500	.49799000	.49758800
17	.49718900	.49679300	.49639900	.49600700	.49561800	.49523200	.49484600	.49446700	.49408800	.49371200
18	.49333800	.49296600	.49259600	.49222800	.49186400	.49150200	.49114100	.49078300	.49042700	.49007300
19	.48872200	.48837200	.48802400	.48767800	.48733500	.48796400	.48765400	.48731700	.48698100	.48664700
20	.48631600	.48598600	.48565800	.48533200	.48500700	.48468500	.48436400	.48404500	.48372700	.48341300
21	.48309800	.48278600	.48247500	.48216700	.48185900	.48155400	.48125000	.48094800	.48064700	.48034700
22	.48005000	.47975400	.47945900	.47916600	.47887400	.47858400	.47829600	.47800800	.47772300	.47743800
23	.47715500	.47687400	.47659300	.47631500	.47603700	.47576100	.47548600	.47521300	.47494100	.47467000
24	.47440000	.47413200	.47386500	.47359900	.47333400	.47307100	.47280900	.47254800	.47228800	.47203000
25	.47177200	.47151600	.47126100	.47100700	.47075500	.47050300	.47025300	.47000300	.46975500	.46950800
26	.46926200	.46901700	.46877300	.46853000	.46828800	.46804700	.46780700	.46756800	.46733100	.46709400
27	.46685800	.46662300	.46638900	.46615700	.46592500	.46569400	.46546400	.46523500	.46500700	.46478000
28	.46455400	.46432800	.46410400	.46388100	.46365800	.46343600	.46321500	.46299600	.46277600	.46255800
29	.46234100	.46212400	.46190900	.46169400	.46148000	.46126700	.46105400	.46084300	.46063200	.46042300
30	.46021300	.46000500	.45979700	.45959100	.45938500	.45917600	.45897500	.45877100	.45856800	.45836600
31	.45816500	.45796400	.45776400	.45756500	.45736600	.45716800	.45697100	.45677500	.45657900	.45638400
32	.45619000	.45599600	.45580300	.45561100	.45541900	.45522800	.45503800	.45484800	.45466000	.45447100
33	.45428400	.45409700	.45391000	.45372500	.45353900	.45335500	.45317100	.45298800	.45280500	.45262400
34	.45244200	.45226100	.45208100	.45190200	.45172300	.45154400	.45136700	.45118900	.45101300	.45083700
35	.45066100	.45048600	.45031200	.45013800	.44996500	.44979200	.44962000	.44944900	.44927800	.44910800
36	.44893700	.44876800	.44859900	.44843000	.44826300	.44809500	.44792800	.44776200	.44759700	.44743100
37	.44726700	.44710200	.44693900	.44677500	.44661300	.44645100	.44628900	.44612800	.44596700	.44580600
38	.44564700	.44548700	.44532900	.44517000	.44501200	.44485500	.44469800	.44454100	.44438500	.44423000
39	.44407400	.44392000	.44376500	.44361200	.44345800	.44330500	.44315300	.44300100	.44284900	.44269800
40	.44254700	.44239700	.44224700	.44209800	.44194900	.44180000	.44165200	.44150400	.44135700	.44121000
41	.44106300	.44091700	.44077100	.44062600	.44048100	.44033600	.44019200	.44004800	.43990500	.43976200
42	.43961900	.43947700	.43933500	.43919400	.43905300	.43891200	.43877200	.43863200	.43849200	.43835300
43	.43821400	.43807500	.43793700	.43780000	.43766200	.43752500	.43738900	.43725200	.43711600	.43698100
44	.43684300	.43671000	.43657600	.43644200	.43630800	.43617400	.43604100	.43590800	.43577600	.43564600
45	.43551100	.43538000	.43524900	.43511800	.43498800	.43485700	.43472800	.43459800	.43446900	.43434000
46	.43421000	.43408300	.43395500	.43382700	.43370000	.43357300	.43344600	.43332000	.43319400	.43306800
47	.43294400	.43281700	.43269200	.43256800	.43244400	.43232000	.43219600	.43207300	.43194900	.43182600
48	.43170400	.43158200	.43146000	.43133800	.43121700	.43109600	.43097500	.43085500	.43073400	.43061400
49	.43049500	.43037500	.43025600	.43013700	.43001900	.42990000	.42978200	.42966300	.42954700	.42943000

UNIT PROGRESS CURVE TABLE 91%

	0	1	2	3	4	5	6	7	8	9
50	.42931300	.42919600	.42908000	.42896400	.42884800	.42873200	.42861700	.42850200	.42838700	.42827200
51	.42815800	.42804400	.42793000	.42781600	.42770300	.42759000	.42747700	.42736400	.42725200	.42714000
52	.42702800	.42691600	.42680500	.42669400	.42658300	.42647200	.42636200	.42625200	.42614200	.42603200
53	.42592300	.42581300	.42570500	.42559600	.42548700	.42537900	.42527100	.42516300	.42505500	.42494800
54	.42484100	.42473400	.42462700	.42452100	.42441400	.42430800	.42420300	.42409700	.42399200	.42388700
55	.42378200	.42367700	.42357200	.42346800	.42336400	.42326000	.42315600	.42305300	.42295000	.42284700
56	.42274400	.42264100	.42253900	.42243700	.42233500	.42223300	.42213100	.42203000	.42192900	.42182800
57	.42172700	.42162600	.42152600	.42142600	.42132600	.42122600	.42112700	.42102700	.42092800	.42082900
58	.42073000	.42063200	.42053300	.42043500	.42033700	.42023900	.42014100	.42004400	.41994700	.41985000
59	.41975300	.41965600	.41956000	.41946300	.41936700	.41927100	.41917500	.41908000	.41898400	.41888900
60	.41879400	.41869900	.41860400	.41851000	.41841600	.41832100	.41822700	.41813400	.41804000	.41794600
61	.41785300	.41776000	.41766700	.41757400	.41748200	.41738900	.41729700	.41720500	.41711300	.41702100
62	.41693000	.41683800	.41674700	.41665600	.41656500	.41647400	.41638400	.41629300	.41620300	.41611300
63	.41602300	.41593300	.41584400	.41575400	.41566500	.41557600	.41548700	.41539800	.41530900	.41522100
64	.41513300	.41504400	.41495600	.41486900	.41478100	.41469300	.41460600	.41451900	.41443100	.41434500
65	.41425800	.41417100	.41408500	.41399800	.41391200	.41382600	.41374000	.41365400	.41356900	.41348300
66	.41339800	.41331300	.41322800	.41314300	.41305800	.41297400	.41288900	.41280500	.41272100	.41263700
67	.41255300	.41246900	.41238600	.41230200	.41221900	.41213600	.41205300	.41197000	.41188700	.41180500
68	.41172200	.41164000	.41155800	.41147600	.41139400	.41131200	.41123100	.41114900	.41106800	.41098600
69	.41090500	.41082400	.41074400	.41066300	.41058200	.41050200	.41042200	.41034100	.41026100	.41018100
70	.41010200	.41002200	.40994300	.40986300	.40978400	.40970500	.40962600	.40954700	.40946800	.40938900
71	.40931100	.40923300	.40915400	.40907600	.40899800	.40892000	.40884300	.40876500	.40868700	.40861000
72	.40853300	.40845600	.40837900	.40830200	.40822500	.40814800	.40807200	.40799500	.40791900	.40784300
73	.40776700	.40769100	.40761500	.40753900	.40746400	.40738800	.40731300	.40723800	.40716300	.40708800
74	.40701300	.40693800	.40686300	.40678900	.40671400	.40664000	.40656600	.40649200	.40641800	.40634400
75	.40627000	.40619600	.40612300	.40604900	.40597600	.40590300	.40583000	.40575700	.40568400	.40561100
76	.40553800	.40546600	.40539300	.40532100	.40524900	.40517700	.40510500	.40503300	.40496100	.40488900
77	.40481800	.40474600	.40467500	.40460400	.40453300	.40446100	.40439000	.40432000	.40424900	.40417800
78	.40410800	.40403700	.40396700	.40389700	.40382700	.40375700	.40368700	.40361700	.40354700	.40347700
79	.40340800	.40333800	.40326900	.40320000	.40313100	.40306200	.40299300	.40292400	.40285500	.40278700
80	.40271800	.40265000	.40258100	.40251300	.40244500	.40237700	.40230900	.40224100	.40217300	.40210600
81	.40203800	.40197000	.40190300	.40183600	.40176900	.40170100	.40163400	.40156700	.40150100	.40143400
82	.40136700	.40130100	.40123400	.40116800	.40110200	.40103500	.40096900	.40090300	.40083700	.40077200
83	.40070600	.40064000	.40057500	.40050900	.40044400	.40037900	.40031300	.40024800	.40018300	.40011800
84	.40005300	.39998900	.39992400	.39985900	.39979500	.39973100	.39966600	.39960200	.39953800	.39947400
85	.39941000	.39934600	.39928200	.39921800	.39915500	.39909100	.39902800	.39896400	.39890100	.39883800
86	.39877500	.39871200	.39864900	.39858600	.39852300	.39846000	.39839800	.39833500	.39827300	.39821000
87	.39814800	.39808600	.39802400	.39796100	.39790000	.39783800	.39777600	.39771400	.39765200	.39759100
88	.39752900	.39746800	.39740700	.39734500	.39728400	.39722300	.39716200	.39710100	.39704000	.39697900
89	.39691900	.39685800	.39679700	.39673700	.39667600	.39661600	.39655600	.39649600	.39643600	.39637600
90	.39631600	.39625600	.39619600	.39613600	.39607700	.39601700	.39595700	.39589800	.39583900	.39577900
91	.39572000	.39566100	.39560200	.39554300	.39548400	.39542500	.39536700	.39530800	.39524900	.39519100
92	.39513200	.39507400	.39501500	.39495700	.39489900	.39484100	.39478300	.39472500	.39466700	.39460900
93	.39455100	.39449400	.39443600	.39437900	.39432100	.39426400	.39420600	.39414900	.39409200	.39403500
94	.39397800	.39392100	.39386400	.39380700	.39375000	.39369300	.39363700	.39358000	.39352400	.39346700
95	.39341100	.39335500	.39329800	.39324200	.39318600	.39313000	.39307400	.39301800	.39296200	.39290600
96	.39285100	.39279500	.39273900	.39268400	.39262900	.39257300	.39251800	.39246300	.39240700	.39235200
97	.39229700	.39224200	.39218700	.39213200	.39207800	.39202300	.39196800	.39191400	.39185900	.39180500
98	.39175000	.39169600	.39164100	.39158700	.39153300	.39147800	.39142500	.39137100	.39131700	.39126300
99	.39120400	.39115600	.39110200	.39104800	.39099500	.39094100	.39088800	.39083500	.39078100	.39072800

TABLE 4.2.0.0-III 95% UNIT PROGRESSIVE CURVE TABLE

UNIT PROGRESS CURVE TABLE

95%

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.95000000	[illegible]	.90250000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	.82711800	.82249500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	.79043000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	.75704600	.75575900	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	.74864400	[illegible]	.74647400	.74542300	.74439200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	.73770800	.73682100	.73594900	.73509200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	.72946700	.72871300	.72796900	.72723700	[illegible]	[illegible]	[illegible]	.72444900	.72372700
8	[illegible]	[illegible]	[illegible]	.72108600	.72044700	.71981100	.71914400	.71857100	.71797100	.71737100
9	[illegible]	[illegible]	[illegible]	.71504100	.71447600	.71391600	[illegible]	[illegible]	.71227600	[illegible]
10	[illegible]	[illegible]	.71017000	.70965800	.70915000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	.70527200	.70480800	.70434900	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	.70125000	[illegible]	[illegible]	.69998000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	.69753700	.69714100	.69674900	.69636000	.69597400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	.69335600	.69299400	.69263400	.69227700	.69192300	[illegible]	.69122000	[illegible]	.69053100
15	[illegible]	[illegible]	.68951300	.68917800	.68884600	[illegible]	[illegible]	[illegible]	[illegible]	.68721900
16	[illegible]	.68658400	.68626900	.68595700	.68564700	.68533600	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	.68352900	.68323400	.68294100	.68265300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	.68066000	.68038300	[illegible]	.67983300	.67956000	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	.67795700	.67769500	.67743500	.67717600	.67691900	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	.67540200	.67515400	.67490700	.67466200	[illegible]	[illegible]	[illegible]	.67369300	[illegible]
21	.67321600	.67297900	.67274400	.67251000	.67227700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	.67067700	.67045300	.67023000	.67000800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	.66848400	.66827100	[illegible]	.66784600	.66763600	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	.66618700	[illegible]	.66578200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	.66380600	.66361300	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	.66247100	.66228400	[illegible]	.66191100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	.66081200	[illegible]	.66045100	.66027100	.66009300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	.65886200	.65868900	[illegible]	.65834400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	.65699200	[illegible]	.65666000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	[illegible]	.65551800	.65535700	[illegible]	.65503700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	[illegible]	.65393500	.65377900	.65362400	.65347000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	.65255500	[illegible]	.65225500	[illegible]	.65195600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
33	[illegible]	[illegible]	[illegible]	[illegible]	.65049100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
35	.64824200	[illegible]	.64796900	[illegible]	.64769800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	[illegible]	[illegible]	.64662700	[illegible]	.64636400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
37	[illegible]	[illegible]	.64532500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
38	[illegible]	[illegible]	[illegible]	[illegible]	.64381000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39	[illegible]	[illegible]	.64282900	[illegible]	.64258700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	.64186800	[illegible]	.64163200	[illegible]	.64139600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
41	.64069700	[illegible]	[illegible]	.64035100	.64023700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42	[illegible]	[illegible]	.63933000	[illegible]	.63910700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	.63844300	.63833300	.63822300	[illegible]	.63800500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	.63735700	.63725000	[illegible]	[illegible]	.63693100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	[illegible]	[illegible]	[illegible]	[illegible]	.63588200	.63577800	[illegible]	[illegible]	[illegible]	[illegible]
46	[illegible]	[illegible]	[illegible]	[illegible]	.63485700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	[illegible]	[illegible]	[illegible]	.63395500	.63385600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
48	[illegible]	[illegible]	.63307200	.63297500	.63287800	.63278100	[illegible]	[illegible]	[illegible]	[illegible]
49	[illegible]	[illegible]	.63211100	[illegible]	.63192100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

UNIT PROGRESS CURVE TABLE

95%

	0	1	2	3	4	5	6	7	8	9
50	.63135600	.63126300	.63117000	.63107700	.63098400	.63089200	.63079900	.63070700	.63061500	.63052400
51	.63043200	.63034100	.63024900	.63015800	.63006800	.62997700	.62988700	.62979600	.62970600	.62961600
52	.62952700	.62943700	.62934800	.62925900	.62917000	.62908100	.62899300	.62890400	.62881500	[illegible]
53	.62864000	.62855200	.62846500	.62837700	.62829000	.62820300	.62811700	.62803000	.62794300	.62785700
54	.62777100	.62768500	.62759900	.62751400	.62742800	.62734300	.62725800	.62717300	.62708800	.62700400
55	.62691400	.62683500	.62675100	.62666700	.62658300	.62649900	.62641600	.62633300	.62625000	.62616700
56	.62608400	.62600100	.62591900	.62583600	.62575400	.62567200	.62559000	.62550900	.62542700	.62534600
57	.62526400	.62518300	.62510200	.62502200	.62494100	.62486000	.62478000	.62470000	.62462000	.62454000
58	.62446000	.62438100	.62430100	.62422200	.62414300	.62406400	.62398500	.62390600	.62382700	.62374900
59	.62367100	.62359300	.62351500	.62343700	.62335900	.62328100	.62320400	.62312700	.62304900	.62297200
60	.62289500	.62281900	.62274200	.62266600	.62258900	.62251300	.62243700	.62236100	.62228500	.62221000
61	.62213400	.62205900	.62198300	.62190800	.62183300	.62175800	.62168400	[illegible]	.62153400	.62146000
62	.62138600	.62131200	.62123800	.62116400	.62109000	.62101700	.62094300	.62087000	.62079700	.62072400
63	.62065100	.62057800	.62050500	.62043200	.62036000	.62028800	.62021500	.62014300	.62007100	.61999900
64	.61992800	.61985600	.61978500	.61971300	.61964200	.61957100	.61950000	.61942900	.61935800	.61928700
65	.61921700	.61914600	.61907600	.61900600	.61893600	.61886600	.61879600	.61872600	.61865700	.61858700
66	.61851800	.61844800	.61837900	.61831000	.61824100	.61817200	.61810400	.61803500	.61796600	.61789800
67	.61783000	.61776200	.61769300	.61762600	.61755800	.61749000	.61742200	.61735500	.61728700	.61722000
68	.61715300	.61708600	.61701900	.61695200	.61688500	.61681800	.61675200	.61668500	.61661900	.61655300
69	.61648600	.61642000	.61635400	.61628900	.61622300	.61615700	.61609200	.61602600	.61596100	.61589600
70	.61583000	.61576500	.61570000	.61563500	.61557100	.61550600	.61544200	.61537700	.61531300	.61524800
71	.61518400	.61512000	.61505600	.61499200	.61492900	.61486500	.61480100	.61473800	.61467400	[illegible]
72	.61454800	.61448500	.61442200	.61435900	.61429600	.61423300	.61417100	.61410800	.61404600	.61398300
73	.61392100	.61385900	.61379700	.61373500	.61367300	.61361100	.61354900	.61348800	.61342600	.61336500
74	.61330300	.61324200	.61318100	.61312000	[illegible]	.61299800	.61293700	.61287600	.61281500	.61275500
75	.61269400	.61263400	.61257400	.61251300	.61245300	.61239300	.61233300	.61227300	.61221300	.61215400
76	.61209400	.61203400	.61197500	.61191600	.61185600	.61179700	.61173800	.61167900	.61162000	.61156100
77	.61150200	.61144300	.61138500	.61132600	.61126800	.61120900	.61115100	.61109300	.61103500	.61097700
78	.61091900	.61086100	.61080300	.61074500	.61068700	.61063000	.61057200	.61051500	.61045700	.61040000
79	.61034300	.61028600	.61022900	.61017200	.61011500	.61005800	.61000100	.60994500	.60988800	.60983100
80	.60977500	.60971900	.60966200	.60960600	.60955000	.60949400	.60943800	.60938200	.60932600	.60927000
81	.60921500	.60915900	.60910400	.60904800	.60899300	.60893700	.60888200	.60882700	.60877200	.60871700
82	.60866200	.60860700	.60855200	.60849700	[illegible]	.60839800	.60833400	.60827900	.60822500	.60817000
83	.60811600	.60806200	.60800800	.60795400	.60790000	.60784600	.60779200	.60773800	.60768500	.60763100
84	.60757700	.60752400	.60747100	.60741700	.60736400	.60731100	.60725800	.60720400	.60715100	.60709800
85	.60704600	.60699300	.60694000	.60688700	.60683500	.60678200	.60673000	.60667700	.60662500	.60657300
86	.60652000	.60646800	.60641600	.60636400	.60631200	.60626000	.60620800	.60615700	.60610500	.60605300
87	.60600200	.60595000	.60589900	.60584700	.60579600	.60574500	.60569400	.60564200	.60559100	.60554000
88	.60548900	.60543900	.60538800	.60533700	.60528600	.60523600	.60518500	.60513500	.60508400	.60503400
89	.60498300	.60493300	.60488300	.60483300	.60478300	.60473300	.60468300	.60463300	.60458300	.60453300
90	.60448300	.60443400	.60438400	.60433500	.60428500	.60423600	.60418600	.60413700	.60408800	.60403800
91	.60398900	.60394000	.60389100	.60384200	.60379300	.60374400	.60369600	.60364700	.60359800	.60355000
92	.60350100	.60345200	.60340400	.60335600	.60330700	.60325900	.60321100	.60316300	.60311400	.60306600
93	.60301800	.60297000	.60292300	.60287500	.60282700	.60277900	.60273100	.60268400	.60263600	.60258900
94	.60254100	.60249400	.60244700	.60239900	.60235200	.60230500	.60225800	.60221100	.60216400	.60211700
95	.60207000	.60202300	.60197600	.60192900	.60188200	.60183600	.60178900	.60174300	.60169600	.60165000
96	.60160300	.60155700	.60151100	.60146400	.60141800	.60137200	.60132600	.60128000	.60123400	.60118800
97	.60114200	.60109600	.60105000	.60100500	.60095900	.60091300	.60086800	.60082200	.60077700	.60073100
98	.60068600	.60064100	.60059500	.60055000	.60050500	.60046000	.60041500	.60037000	.60032500	.60028000
99	.60023500	.60019000	.60014500	.60010100	.60005600	.60001100	.59996700	.59992200	.59987700	.59983100

TABLE 4.2.0.0-IV 91% CUMULATIVE PROGRESSIVE CURVE TABLE

CUMULATIVE PROGRESS CURVE TABLE

91%

	0	1	2	3	4	5	6	7	8	9
0		1.00000000	1.91000000	2.77115700	3.59925700	4.40259300	5.18624600	5.95363300	6.70720400	7.44879500
1	8.17983000	8.90144700	9.61457100	10.31907000	11.01829300	11.71009100	12.39584100	13.07595700	13.75080500	14.42070600
2	15.08594800	15.74678900	16.40346000	17.05617100	17.70511400	18.35046200	18.99237600	19.63100200	20.26647500	20.89892200
3	21.52845800	22.15519200	22.77922400	23.40064900	24.01955300	24.63602500	25.25013600	25.86196200	26.47157200	27.07903100
4	27.68440100	28.28774100	28.88910600	29.48854900	30.08612000	30.68186600	31.27583300	31.86806500	32.45860300	33.04748600
5	33.63475300	34.22044000	34.80458100	35.38721000	35.96835900	36.54805900	37.12634000	37.70323000	38.27875600	38.85294500
6	39.42582300	39.99741400	40.56774200	41.13682900	41.70469800	42.27137100	42.83684800	43.40120900	43.96441300	44.52550000
7	45.08748700	45.64739300	46.20623400	46.76402700	47.32078900	47.87653500	48.43128000	48.98503900	49.53782700	50.08965800
8	50.64054500	51.19050200	51.73954100	52.28767600	52.83491800	53.38128000	53.92677300	54.47140900	55.01519800	55.55815200
9	56.10028100	56.64159600	57.18210600	57.72182200	58.26075300	58.79890900	59.33629800	59.87293000	60.40881400	60.94395800
10	61.47837100	62.01206100	62.54503600	63.07730400	63.60887300	64.13975000	64.66994300	65.19945900	65.72830500	66.25648800
11	66.78401500	67.31089300	67.83712900	68.36272900	68.88769900	69.41204500	69.93577400	70.45889200	70.98140400	71.50331700
12	72.02463600	72.54536600	73.06551400	73.58508400	74.10408200	74.62251300	75.14038200	75.65769500	76.17445600	76.69067000
13	77.20634200	77.72147700	78.23607900	78.75015300	79.26370300	79.77673400	80.28925000	80.80125500	81.31275400	81.82375100
14	82.33425000	82.84425400	83.35376800	83.86279600	84.37134200	84.87940900	85.38700100	85.89412200	86.40077500	86.90696400
15	87.41269300	87.91796500	88.42278300	88.92715100	89.43107200	89.93455000	90.43758700	90.94018700	91.44235300	91.94408800
16	92.44539500	92.94627700	93.44673800	93.94678000	94.44640600	94.94561900	95.44442200	95.94281700	96.44080700	96.93839500
17	97.43558400	97.93237700	98.42877600	98.92478300	99.42040100	99.91563300	100.41048100	100.90494800	101.39903600	101.89274800
18	102.38608600	102.87905200	103.37164800	103.86387700	104.35574100	104.84724300	105.33838400	105.82916700	106.31959400	106.80966[illegible]00
19	107.29938900	107.78876100	108.27778500	108.76646400	109.25479900	109.74279300	110.23044700	110.71776400	111.20474500	111.69139200
20	112.17770800	112.66369400	113.14935200	113.63468400	114.11969100	114.60437600	115.08874000	115.57278500	116.05651200	116.53992400
21	117.02302200	117.50580800	117.98828300	118.47045000	118.95230900	119.43386300	119.91511300	120.39606100	120.87670800	121.35705500
22	121.83710500	122.31685900	122.79631800	123.27548400	123.75435800	124.23294200	124.71123800	125.18924800	125.66696900	126.14440700
23	126.62156200	127.09843800	127.57502800	128.05134400	128.52738100	129.00314200	129.47862800	129.95384100	130.42878200	130.90345200
24	131.37785200	131.85198400	132.32584900	132.79944800	133.27278200	133.74585300	134.21866200	134.69121000	135.16349800	135.63552800
25	136.10730000	136.57881600	137.05007700	137.52108400	137.99183900	138.46234200	138.93259500	139.40259800	139.87235300	140.34186100
26	140.81112300	141.28014000	141.74891300	142.21744300	142.68573100	143.15377800	143.62158500	144.08915300	144.55648400	145.02357800
27	145.49043600	145.95705900	146.42344800	146.88960500	147.35553000	147.82122400	148.28668800	148.75192500	149.21693000	149.68171000
28	150.14626400	150.61059200	151.07469600	151.53857700	152.00223500	152.46567100	152.92888600	153.39188200	153.85465800	154.31721600
29	154.77955700	155.24168100	155.70359000	156.16528400	156.62676400	157.08803100	157.54908500	158.00992800	158.47056000	158.93098200
30	159.39119500	159.85120000	160.31099700	160.77058800	161.22997300	161.68915200	162.14812700	162.60689800	163.06546600	163.52383700
31	163.98199700	164.43996100	164.89772500	165.35529000	165.81265600	166.26982400	166.72679500	167.18357000	167.64014900	168.09653300
32	168.55272300	169.00871900	169.46452200	169.92013300	170.37555200	170.83078000	171.28581800	171.74066600	172.19532600	172.64979700
33	173.10408100	173.55817800	174.01208800	174.46581300	174.91935200	175.37270700	175.82587800	176.27886600	176.73167100	177.18429500
34	177.63673700	178.08899800	178.54107900	178.99298100	179.44470400	179.89624800	180.34761500	180.79880400	181.24981700	181.70065400
35	182.15131500	182.60180100	183.05211300	183.50225100	183.95221600	184.40200800	184.85162800	185.30107700	185.75035500	186.19946200
36	186.64839900	187.09716700	187.54576600	187.99419600	188.44245900	188.89055400	189.33848300	189.78624500	190.23384200	190.68127300
37	191.12854000	191.57564200	192.02258100	192.46935600	192.91596900	193.36242000	193.80870900	194.25483700	194.70080400	195.14661000
38	195.59225700	196.03774400	196.48307300	196.92824300	197.37325500	197.81811000	198.26280800	198.70734900	199.15173400	199.59596400
39	200.04003800	200.48395800	200.92772300	201.37133500	201.81479300	202.25809800	202.70125100	203.14425200	203.58710100	204.02979900
40	204.47234600	204.91474300	205.35699000	205.79908800	206.24103700	206.68283700	207.12448900	207.56599300	208.00735000	208.44856000
41	208.88962300	209.33054000	209.77131100	210.21193700	210.65241800	211.09275400	211.53294600	211.97299400	212.41289800	212.85266100
42	213.29228000	213.73175700	214.17109200	214.61028600	215.04933900	215.48825100	215.92702300	216.36565500	216.80414700	217.24250000
43	217.68071400	218.11878900	218.55672600	218.99452800	219.43218800	219.86971300	220.30710200	220.74435400	221.18147000	221.61845100
44	222.05529600	222.49200600	222.92858200	223.36502400	223.80133200	224.23750600	224.67354700	225.10945500	225.54523100	225.98087500
45	226.41638700	226.85176700	227.28701600	227.72213400	228.15712200	228.59197900	229.02670700	229.46130500	229.89577400	230.33011400
46	230.76432500	231.19840800	231.63236300	232.06619000	232.49989000	232.93346300	233.36690900	233.80022900	234.23342300	234.66649100
47	235.09943400	235.53225100	235.96494300	236.39751100	236.82995500	237.26227500	237.69447100	238.12654400	238.55849300	238.99032000
48	239.42202400	239.85360600	240.28506600	240.71640400	241.14762100	241.57871700	242.00969200	242.44054700	242.87128100	243.30189500
49	243.73239000	244.16276500	244.59302100	245.02315800	245.45317700	245.88307700	246.31285900	246.74252400	247.17207100	247.60150100
50	248.03081400	248.46001000	248.88909000	249.31805400	249.74690200	250.17563400	250.60425100	251.03275300	251.46114000	251.88941200
51	252.31757000	252.74561400	253.17354400	253.60136000	254.02905300	254.45665300	254.88413000	255.31149400	255.73874600	256.16588600
52	256.59291400	257.01983000	257.44663500	257.87332900	258.29991200	258.72638400	259.15274600	259.57899800	260.00514000	260.43117200
53	260.85709500	261.28290800	261.70861300	262.13420900	262.55969600	262.98507500	263.41034600	263.83550900	264.26056400	264.68551200
54	265.11035300	265.53508700	265.95971400	266.38423500	266.80864900	267.23295700	267.65716000	268.08125700	268.50524900	268.92913500
55	269.35291700	269.77659400	270.20016600	270.62363400	271.04699800	271.47025800	271.89341400	272.31646700	272.73941700	273.16226400
56	273.58500800	274.00764900	274.43018800	274.85262500	275.27496000	275.69719300	276.11932400	276.54135400	276.96328300	277.38511100
57	277.80683800	278.22846400	278.64999000	279.07141600	279.49274200	279.91396800	280.33509500	280.75612200	281.17705000	281.59787900
58	282.01860900	282.43924100	282.85977400	283.28020900	283.70054600	284.12078500	284.54092600	284.96097000	285.38091700	285.80076700
59	286.22052000	286.64017600	287.05973600	287.47919900	287.89856600	288.31783700	288.73701200	289.15609200	289.57507600	289.99396500
60	290.41275900	290.83145800	291.25006200	291.66857200	292.08698800	292.50530900	292.92353600	293.34167000	293.75971000	294.17765600
61	294.59550900	295.01326900	295.43093600	295.84851000	296.26599200	296.68338100	297.10067800	297.51788300	297.93499600	298.35201700
62	298.76894700	299.18578500	299.60253200	300.01918800	300.43575300	300.85222700	301.26861100	301.68490400	302.10110700	302.51722000
63	302.93324300	303.34917600	303.76502000	304.18077400	304.59643900	305.01201500	305.42750200	305.84290000	306.25820900	306.67343000
64	307.08856300	307.50360700	307.91856300	308.33343200	308.74821300	309.16290600	309.57751200	309.99203100	310.40646200	310.82080700
65	311.23506500	311.64923600	312.06332100	312.47731000	312.89123100	313.30505700	313.71878700	314.13245100	314.54602000	314.95950300
66	315.37290100	315.78621400	316.19944200	316.61258500	317.02564300	317.43861700	317.85150600	318.26431100	318.67703200	319.08966900
67	319.50222200	319.91469100	320.32707700	320.73937900	321.15159800	321.56373400	321.97578700	322.38775700	322.79964400	323.21144900
68	323.62317100	324.03481100	324.44636900	324.85784500	325.26923900	325.68055100	326.09178200	326.50293100	326.91399900	327.32498500
69	327.73589000	328.14671400	328.55745800	328.96812100	329.37870500	329.78920500	330.19962700	330.60996800	331.02022900	331.43041000
70	331.84051200	332.25053400	332.66047700	333.07034000	333.48012400	333.88982900	334.29945500	334.70900200	335.11847000	335.52785900
71	335.93717000	336.34640300	336.75555700	337.16463300	337.57363100	337.98255100	338.39139400	338.80015900	339.20884600	339.61745600
72	340.02598900	340.43444500	340.84282400	341.25112600	341.65935100	342.06749900	342.47557100	342.88356600	343.29148500	343.69932800
73	344.10709500	344.51478500	344.92240100	345.32994000	345.73740400	346.14479200	346.55210500	346.95934300	347.36650600	347.77359400
74	348.18060700	348.58754500	348.99440800	349.40119700	349.80791100	350.21455100	350.62111700	351.02760900	351.43402700	351.84037100
75	352.24664100	352.65283700	353.05896000	353.46500900	353.87098500	354.27688800	354.68271800	355.08847500	355.49415900	355.89977000
76	356.30530800	356.71077400	357.11616700	357.52148800	357.92673700	358.33191400	358.73701900	359.14205200	359.54701300	359.95190200
77	360.35672000	360.76146600	361.16614100	361.57074500	361.97527800	362.37973900	362.78412900	363.18844900	363.59269800	363.99687600
78	364.40098400	364.80502100	365.20898800	365.61288500	366.01671200	366.42046900	366.82415600	367.22777300	367.63132000	368.03479700
79	368.43820500	368.84154300	369.24481200	369.64801200	370.05114300	370.45420500	370.85719800	371.26012200	371.66297700	372.06576400
80	372.46848200	372.87113200	373.27371300	373.67622600	374.07867100	374.48104800	374.88335700	375.28559800	375.68777100	376.08987700
81	376.49191500	376.89388500	377.29578800	377.69762400	378.09939300	378.50109400	378.90272800	379.30429500	379.70579600	380.10723000
82	380.50859700	380.90989800	381.31113200	381.71230000	382.11340200	382.51443700	382.91540600	383.31630900	383.71714600	384.11791800
83	384.51862400	384.91926400	385.31983900	385.72034800	386.12079200	386.52117100	386.92148400	387.32173200	387.72191500	388.12203300
84	388.52208600	388.92207500	389.32199900	389.72185800	390.12165300	390.52138400	390.92105000	391.32065200	391.72019000	392.11966400
85	392.51907400	392.91842000	393.31770200	393.71692000	394.11607500	394.51516600	394.91419400	395.31315800	395.71205900	396.11089700
86	396.50967200	396.90838400	397.30703300	397.70561900	398.10414200	398.50260200	398.90100000	399.29933500	399.69760800	400.09581800
87	400.49396600	400.89205200	401.29007600	401.68803700	402.08593700	402.48377500	402.88155100	403.27926500	403.67691700	404.07450800
88	404.47203700	404.86950500	405.26691200	405.66425700	406.06154100	406.45876400	406.85592600	407.25302700	407.65006700	408.04704600
89	408.44396500	408.84082300	409.23762000	409.63435700	410.03103300	410.42764900	410.82420500	411.22070100	411.61713700	412.01351300
90	412.40982900	412.80608500	413.20228100	413.59841700	413.99449400	414.39051100	414.78646800	415.18236600	415.57820500	415.97398400
91	416.36970400	416.76536500	417.16096700	417.55651000	417.95199400	418.34741900	418.74278600	419.13809400	419.53334300	419.92853400
92	420.32366600	420.71874000	421.11375500	421.50871200	421.9036[illegible]	422.29845200	422.69323900	423.08796000	423.48262700	423.87723600
93	424.27178700	424.66628100	425.06071700	425.45509600	425.84941700	426.24368100	426.63788700	427.03203600	427.42612800	427.82016300
94	428.21414100	428.60806200	429.00192600	429.39573300	429.78948300	430.18317600	430.57681300	430.97039300	431.36391700	431.75738400
95	432.15079500	432.54415000	432.93744800	433.33069000	433.72387600	434.11700600	434.51008000	434.90309800	435.29606000	435.68896600
96	436.08181700	436.47461200	436.86735100	437.26003500	437.65266400	438.04523700	438.43775500	438.83021800	439.22262500	439.61497700
97	440.00727400	440.39951600	440.79170300	441.18383500	441.57591300	441.96793600	442.35990400	442.75181800	443.14367700	443.53548200
98	443.92723200	444.31892800	444.71056900	445.10215600	445.49[illegible]	445.88516800	446.27659300	446.66796400	447.05928100	447.45054400
99	447.84175300	448.23290800	448.62401100	449.01505800	449.40[illegible]	449.7[illegible]	450.18788100	450.57871600	450.[illegible]	451.36022700

TABLE 4.2.0.0-V 95% CUMULATIVE PROGRESSIVE CURVE TABLE

CUMULATIVE PROGRESS CURVE TABLE 95%

	0	1	2	3	4
		1.00000000	1.65000000	2.87191900	3.77441900
1	8.95449500	9.79190200	10.62393400	11.45105200	12.27364700
2	17.13023800	17.92851600	18.72405400	19.51697800	20.30740800
3	25.00317500	25.77877500	26.55255700	27.32457800	28.09489500
4	32.68378800	33.44350700	34.20187300	34.95891900	35.71467800
5	40.22385600	40.97140400	41.71787800	42.46330100	43.20769300
6	47.65349400	48.39120200	49.12802300	49.86397200	50.59906400
7	54.99238200	55.72184900	56.45056200	57.17853100	57.90576800
8	62.25437600	62.97676500	63.69849800	64.41958400	65.14003100
9	69.44974100	70.16593400	70.88154800	71.59658900	72.31106500
10	76.58618900	77.29707700	78.00724700	78.71690500	79.42605500
11	83.67059200	84.37633200	85.08160400	85.78641200	86.49076100
12	90.70744300	91.40669300	92.10951600	92.80991500	93.50989500
13	97.70116300	98.39830400	99.09505300	99.79141300	100.48738700
14	104.65529700	105.34865300	106.04164700	106.73428100	107.42655800
15	111.57286400	112.26271900	112.95223200	113.64141000	114.33025600
16	118.45648400	119.14306800	119.82933700	120.51529400	121.20094100
17	125.30841300	125.99194200	126.67517600	127.35811700	128.04076700
18	132.13065100	132.81131100	133.49169400	134.17180100	134.85163400
19	138.92496000	139.60291700	140.28061200	140.95804700	141.63522300
20	145.69291700	146.36831900	147.04347300	147.71838000	148.39304200
21	152.43593100	153.10891000	153.78165400	154.45416400	155.12644100
22	159.15527100	159.82594800	160.49640100	161.16663100	161.83663900
23	165.85208900	166.52057300	167.18884400	167.85690200	168.52474800
24	172.52743400	173.19382500	173.86001200	174.52599600	175.19177800
25	179.18226700	179.84665000	180.51085000	181.17484900	181.83865500
26	185.81746500	186.47993600	187.14222000	187.80431700	188.46622800
27	192.43383400	193.09446500	193.75491600	194.41518700	195.07528000
28	199.03212500	199.69048700	200.34967600	201.00819200	201.66653600
29	205.61702600	206.27018500	206.92717700	207.58400300	208.24066300
30	[illegible]	212.83269900	213.48805600	214.14325300	214.79829000
31	218.72518900	219.37912400	220.03790300	220.68652700	221.33999700
32	225.25760600	225.91601100	226.56226600	227.21437100	227.86632100
33	231.77445600	232.42588100	233.07666100	233.72729600	234.37778700
34	[illegible]	238.92722000	239.57657700	240.22578500	240.87485700
35	[illegible]	245.41446500	246.06245400	246.71028700	247.35798500
36	[illegible]	251.88990000	252.53473300	253.18122800	253.82759200
37	257.77030300	258.34948600	258.99381100	259.63900800	260.28407700
38	264.15182500	264.74600700	265.44006800	266.08400300	266.72781300
39	[illegible]	271.23103500	271.87386400	272.51657200	273.15915900
40	[illegible]	277.65340400	278.29554100	278.93705500	279.57845100
41	[illegible]	284.06495600	284.70542200	285.34577300	285.98601000
42	[illegible]	290.46048200	291.10181200	291.74303000	292.38213700
43	[illegible]	296.85278100	297.49100400	298.12911800	298.76712300
44	[illegible]	303.23013200	303.86727500	304.50431200	305.14124300
45	[illegible]	309.59580300	310.23289200	310.86887700	311.50475900
46	315.31788300	315.95304500	316.58810500	317.22306400	317.85792100
47	321.66494900	322.29910300	322.93315800	323.56711300	324.20096900
48	328.00203900	328.63520800	329.26828000	329.90125500	330.53413300
49	334.32937800	334.96158400	335.59369500	336.22571100	336.85763200

CUMULATIVE PROGRESS CURVE TABLE 95%

	5	6	7	8	9	
	4.66213900	5.53796200	6.40385100	7.26122600	8.11118100	
1	13.09205300	13.90655900	14.71741900	15.52485700	16.32907100	1
2	21.09545400	21.88121600	22.66478700	23.44625200	24.22569000	2
3	28.86356200	29.63062800	30.39614000	31.16014300	31.92267900	3
4	36.46918200	37.22245900	37.97453900	38.72544800	39.47522200	4
5	43.95107500	44.69346700	45.43488700	46.17535300	46.91488300	5
6	51.33331300	52.06573300	52.79933700	53.53117600	54.26214900	6
7	58.63228300	59.35808600	60.08318700	60.80759800	61.53132300	7
8	65.85984800	66.57904200	67.29762100	68.01559200	68.73296300	8
9	73.02498100	73.73834400	74.45116000	75.16343600	75.87517700	9
10	80.13470300	80.84285500	81.55051500	82.25768800	82.96437900	10
11	87.19465500	87.89809800	88.60109400	89.30364800	90.00576300	11
12	94.20945900	94.90861100	95.60734400	96.30569100	97.00362600	12
13	101.18297800	101.87818900	102.57302400	103.26748500	103.96157500	13
14	108.11848100	108.81005200	109.50127400	110.19214900	110.88268000	14
15	115.01877200	115.70696100	116.39482400	117.08236400	117.76958300	15
16	121.88627900	122.57131100	123.25603800	123.94046300	124.62458700	16
17	128.72312800	129.40520100	130.08698800	130.76849100	131.44971100	17
18	135.53119400	136.21048300	136.88950300	137.56825500	138.24674000	18
19	142.31214100	142.98880300	143.66521000	144.34136400	145.01726600	19
20	149.06746000	149.74163500	150.41556800	151.08926100	151.76271500	20
21	155.79848600	156.47030000	157.14188400	157.81324000	158.48436900	21
22	162.50642700	163.17599500	163.84534400	164.51447500	165.18339000	22
23	169.19238400	169.85961000	170.52702700	171.19403800	171.86083800	23
24	175.85735800	176.52273700	177.18791700	177.85289800	178.51768100	24
25	182.50226800	183.16568600	183.82891700	184.49195600	185.15480500	25
26	189.12785400	189.78949600	190.45085400	191.11202900	191.77302700	26
27	195.73519500	196.39493300	197.05449400	197.71387900	198.37308900	27
28	202.32470500	202.98271100	203.64054300	204.29820600	204.95570000	28
29	208.89715800	209.55348900	210.20965600	210.86566000	211.52150200	29
30	215.45316800	216.10788700	216.76244800	217.41685200	218.07109900	30
31	221.99331300	222.64647600	223.29948600	223.95234400	224.60505100	1
32	228.51813400	229.16979300	229.82130400	230.47266800	231.12388500	32
33	235.02813400	235.67833800	236.32839900	236.97831700	237.62809300	33
34	241.52370000	242.17258400	242.82124000	243.46975700	244.11813700	34
35	248.00554700	248.65297500	249.30026800	249.94742700	250.59445300	35
36	254.47382500	255.11992700	255.76589800	256.41173900	257.05745100	36
37	260.92901800	261.57383200	262.21852000	262.86308100	263.50751600	37
38	267.37149900	268.01506200	268.65850200	269.30181900	269.94501300	38
39	273.80162500	274.44397100	275.08619700	275.72830400	276.37029100	39
40	280.21973000	280.86089200	281.50193700	282.14286600	282.78367800	40
41	286.62613200	287.26614000	287.90603500	288.54581600	289.18548400	41
42	293.02113200	293.66001600	294.29878900	294.93745200	295.57600500	42
43	299.40502000	300.04280800	300.68048800	301.31806000	301.95552500	43
44	305.77806800	306.41478700	307.05140000	307.68790800	308.32431100	44
45	312.14053700	312.77621200	313.41178400	314.04725300	314.68261900	45
46	318.49267700	319.12733200	319.76188700	320.39634100	321.03069500	46
47	324.83472700	325.46838600	326.10194600	326.73540800	327.36877200	47
48	331.16681400	331.79959900	332.43218800	333.06468000	333.69707700	48
49	[illegible]	338.12119000	338.75282800	339.38437200	340.01582200	49

CUMULATIVE PROGRESS CURVE TABLE 95%

	0	1	2	3	4
50	[illegible]	[illegible]	[illegible]	342.54066800	343.17167200
51	[illegible]	[illegible]	[illegible]	348.84638400	349.47645700
52	[illegible]	[illegible]	[illegible]	355.14301000	355.77218000
53	[illegible]	[illegible]	[illegible]	361.43073600	362.05902800
54	[illegible]	[illegible]	[illegible]	367.70974500	368.33717300
55	[illegible]	[illegible]	[illegible]	[illegible]	374.60679400
56	[illegible]	[illegible]	[illegible]	380.24229400	380.86840500
57	[illegible]	[illegible]	385.57114800	386.49616800	387.12110900
58	[illegible]	[illegible]	[illegible]	392.41973000	393.36611600
59	[illegible]	[illegible]	[illegible]	398.97986300	399.60322200
60	[illegible]	[illegible]	[illegible]	405.20997700	405.83258600
61	[illegible]	[illegible]	410.71054800	411.43245600	412.05428900
62	[illegible]	416.40503200	417.02627000	417.64743400	418.26852400
63	[illegible]	422.61410400	423.23460900	423.85504100	424.47540100
64	428.19604500	428.81590100	429.43568600	430.05539900	430.67504100
65	434.39140300	435.01054800	435.62962500	436.24863100	436.86756700
66	440.57971700	[illegible]	441.81654400	442.43485400	443.05309500
67	446.76110000	447.37886200	447.99655500	448.61418100	449.23173900
68	[illegible]	453.55275200	454.16977100	454.78672300	455.40360800
69	459.10352100	459.71994100	460.33629500	460.95258400	461.56880700
70	465.26476900	465.88053400	466.49623400	467.11186900	467.72744000
71	471.41951000	472.03463000	472.64968800	473.26467800	473.87960700
72	477.56764400	478.18232000	478.79675100	479.41111000	480.02546000
73	483.70986800	484.32372700	484.93752400	485.55125000	486.16495200
74	489.84567400	490.45891600	491.07209700	491.68521700	492.29827600
75	495.97535100	496.58798500	497.20055900	497.81307200	498.42552500
76	502.09898500	502.71101900	503.32299400	503.93491000	504.54676600
77	508.21666300	508.82810600	509.43949100	510.05081700	510.66208500
78	514.32846900	514.93933000	515.55013300	516.16087000	516.77154500
79	520.43448200	521.04476800	521.65498700	522.26516000	522.87528000
80	526.53478200	527.14450100	527.75416300	528.36376000	528.97331900
81	532.62944400	533.23860300	533.84770700	534.45675900	535.06574800
82	538.71854500	539.32715200	539.93570400	540.54420100	541.15264400
83	544.80215600	545.41021800	546.01822600	546.62618000	547.23408000
84	550.88034400	551.48787300	552.09534400	552.70276100	553.31012500
85	556.95319300	557.56018600	558.16712600	558.77401300	559.38084800
86	563.02075500	563.62722300	564.23363900	564.84000300	565.44631500
87	569.08330000	569.68905000	570.29464900	570.90008600	571.50535200
88	575.14029300	575.74573200	576.35112000	576.95643700	577.56174800
89	581.19240000	581.79733900	582.40221600	583.00704000	583.61182000
90	587.23948000	587.84391400	588.44827800	589.05263300	589.65691800
91	593.28159200	593.88553200	594.48947500	595.09326800	595.69705800
92	599.31879400	599.92224600	600.52565000	601.12900600	601.73231100
93	605.35114400	605.95411400	606.55703700	607.15991200	607.76279300
94	611.37869900	611.98119500	612.58364000	613.18603900	613.78839100
95	617.40151600	618.00353000	618.60551500	619.20744600	619.80933600
96	623.41984300	624.02120000	624.62271100	625.22418800	625.82561000
97	629.43313900	630.03423100	630.63528100	631.23630000	631.83724500
98	635.44204200	636.04268300	636.64327800	637.24382800	637.84433100
99	641.44641800	642.04660000	642.64675300	643.24684400	643.84691800

CUMULATIVE PROGRESS CURVE TABLE 95%

	5	6	7	8	9	
50	343.80256400	344.43336300	345.06407000	345.69468500	346.32520900	50
51	350.10643400	350.73632100	351.36611700	351.99582300	352.62543900	51
52	356.40126100	357.03025400	357.65915800	358.28797400	358.91670200	52
53	362.68722900	363.31534600	363.94337600	364.57131900	365.19917600	53
54	368.96451600	369.59177400	370.21894700	370.84603500	371.47303900	54
55	375.23329300	375.85970900	376.48604200	377.11229200	377.73845900	55
56	381.49372500	382.11931500	382.74482400	383.37025100	383.99559700	56
57	387.74596900	388.37074900	388.99544900	389.62006900	390.24460900	57
58	393.99018000	394.61416500	395.23807100	395.86189800	396.48564700	58
59	400.22650300	400.84970700	401.47283600	402.09588300	402.71885500	59
60	406.45507900	407.07751600	407.69987700	408.32216200	408.94437200	60
61	412.67604700	413.29773100	413.91934000	414.54087400	415.16233400	61
62	418.88954100	419.51048400	420.13135400	420.75215100	421.37287500	62
63	425.09568900	425.71590400	426.33604700	426.95611800	427.57611700	63
64	431.29461200	431.91411200	432.53354100	433.15289900	433.77218600	64
65	437.48643300	438.10522900	438.72395500	439.34261200	439.96119900	65
66	443.67126700	444.28937100	444.90740600	445.52537200	446.14327000	66
67	449.84922900	450.46665100	451.08400600	451.70129100	452.31851300	67
68	456.02042600	456.63717800	457.25386300	457.87048200	458.48703500	68
69	462.18496400	462.80105600	463.41708200	464.03304300	464.64893900	69
70	468.34294600	468.95838800	469.57376500	470.18907800	470.80432600	70
71	474.49447200	475.10927300	475.72401100	476.33868500	476.95329600	71
72	480.63963900	481.25381000	481.86791800	482.48196400	483.09594700	72
73	486.77854300	487.39209700	488.00558000	488.61900600	489.23237100	73
74	492.91127400	493.52421000	494.13708700	494.74990200	495.36265700	74
75	499.03781800	499.65025100	500.26252400	500.87473700	501.48689100	75
76	505.15856300	505.77030100	506.38198000	506.99360000	507.60516100	76
77	511.27329400	511.88444500	512.49553800	513.10657300	513.71755000	77
78	517.38219500	517.99276700	518.60328200	519.21373900	519.82413900	78
79	523.48534200	524.09534300	524.70528800	525.31517600	525.92500700	79
80	529.58281300	530.19225100	530.80163300	531.41095900	532.02022900	80
81	535.67468500	536.28356700	536.89239400	537.50116600	538.10988300	81
82	541.76103200	542.36936600	542.97764500	543.58587000	544.19404000	82
83	547.84192600	548.44971800	549.05745600	549.66514100	550.27277200	83
84	553.91743800	554.52468400	555.13188600	555.73904900	556.34614700	84
85	559.98763000	560.59436000	561.20103700	561.80766200	562.41423500	85
86	566.05257500	566.65878900	567.26494000	567.87104500	568.47709800	86
87	572.11233700	572.71803100	573.32367300	573.92926400	574.53480400	87
88	578.16697900	578.77216400	579.37729900	579.98238300	580.58741700	88
89	584.21656500	584.82124800	585.42588100	586.03046600	586.63499700	89
90	590.26115400	590.86534000	591.46947700	592.07356500	592.67760300	90
91	596.30080200	596.90440000	597.50814500	598.11174300	598.71529500	91
92	602.33557200	602.93878300	603.54194600	604.14508000	604.74812600	92
93	608.36551800	608.96824000	609.57093300	610.17356900	610.77615800	93
94	614.39069600	614.99295400	615.59516500	616.19732900	616.79944000	94
95	620.41118200	621.01295100	621.61468400	622.21639000	622.81804000	95
96	626.42696500	627.02829100	627.62957100	628.23080900	628.83199300	96
97	632.43815000	633.03902600	633.63986000	634.24062900	634.84135600	97
98	638.44470300	639.04520000	639.64557000	640.24590900	640.84618300	98
99	644.44402100	645.04440000	645.64461000	646.24460700	646.84452000	99

TABLE 4.2.0.0-VI

TOTAL UNIT AND CUMULATIVE COST

MLLV SINGLE STAGE VEHICLE LESS ENGINES (DOLLARS IN MILLIONS)

	(1) SINGLE STAGE VEHICLE COST		(2) FIXED COST		TOTAL COST	
UNIT	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$95	$ 95	$226	$ 226	$321	$ 321
2	87	182	226	452	313	634
3	82	264	125	577	207	841
4	79	343		702	204	1,045
5	77	420		827	202	1,247
6	75	495		952	200	1,447
7	73	568		1,077	198	1,645
8	72	640		1,202	197	1,842
9	71	711		1,327	196	2,038
10	70	780	125	1,452	195	2,232
15	66	$1,117	125	2,077	191	3,194
20	63	1,439		2,702	188	4,141
25	62	1,751		3,327	187	5,078
30	60	2,054		3,952	185	6,006
35	59	2,350		4,577	184	6,927
40	$58	$2,641	$125	$5,202	$183	$7,843

NOTE: (1) Single stage includes cost of structures, system, maintenance, and transportation and engine installation. The composite learning curve value is 91%. First unit cost is $95,000,000.

(2) Fixed costs for each single stage vehicle include: propellant, IU, SDF operations, launch operations, and maintenance and SE&I costs. No learning curve effects were applied in developing these costs.

TABLE 4.2.0.0-VII

TOTAL UNIT AND CUMULATIVE COST

MULTICHAMBER/PLUG AND TOROIDAL ENGINES

FOR THE MLLV SINGLE STAGE VEHICLE

(DOLLARS IN MILLIONS)

VEH NBR	(1) * MULTICHAMBER PLUG ENGINE COST		(2) TOROIDAL					
			**286K THRUST 1200 PSI		***1M THRUST 1200 PSI		***1M THRUST 2000 PSI	
	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$50.8	$ 50.8	$32.8	$ 32.8	$23.2	$ 23.2	$23.5	$ 23.5
2	46.0	96.8	29.8	62.6	21.3	44.5	21.6	45.1
3	44.3	141.1	28.6	91.2	20.5	65.0	20.7	65.8
4	43.2	184.3	27.9	119.1	20.0	85.0	20.2	86.0
5	42.5	226.8	27.4	146.5	19.6	104.6	19.9	105.9
6	41.8	268.6	27.0	173.5	19.3	123.9	19.6	125.5
7	41.3	309.9	26.7	200.2	19.1	143.0	19.3	144.8
8	40.8	350.7	26.4	226.6	18.9	161.9	19.1	163.9
9	40.1	391.2	26.1	252.7	18.7	180.6	19.0	182.9
10	$40.1	$ 431.3	$25.9	$ 278.6	$18.6	$199.2	$18.8	$201.7
15	$39.3	$ 628.1	$25.4	$ 405.8	$18.2	$290.3	$18.4	$293.9
20	38.3	820.0	24.7	529.7	17.7	379.1	17.9	383.8
25	37.6	1,008.4	24.3	651.4	17.4	466.2	17.6	472.0
30	37.0	1,193.4	23.9	771.2	17.1	552.1	17.4	559.0
35	36.7	1,377.2	23.6	889.6	16.9	636.9	17.1	644.9
40	$36.2	$1,558.5	$23.4	$1,006.8	$16.7	$720.8	$16.9	$729.8
	*Blocks of 24 each		**Blocks of 28		***Blocks of 8		*** Blocks of 8	

NOTE: (1) Multichamber/plug engines are based on an estimated first unit cost of $2,500.000 and a learning curve value of 95%.

(2) First unit costs for toroidal engines are $1,400,000, $3,200,000 and $3,240,000, respectively. The learning curve value is 95%.

TABLE 4.2.0.0-VIII

TOTAL UNIT AND CUMULATIVE COST
MLLV INJECTION STAGE ENGINE MODULE
LESS ENGINES

(DOLLARS IN MILLIONS)

	(1) ENGINE MODULE COST		(2) FIXED COST		TOTAL COST	
UNIT	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$16.7	$ 16.7	$16.6	$ 16.6	$33.3	$ 33.3
2	15.2	31.9	16.6	33.2	31.8	65.1
3	14.4	46.3	4.7	37.9	19.1	84.2
4	13.8	60.1		42.6	18.5	102.7
5	13.4	73.5		47.3	18.1	120.8
6	13.1	86.6		52.0	17.8	138.6
7	12.8	99.4		56.7	17.5	156.1
8	12.6	112.0		61.4	17.3	173.4
9	12.4	124.4		66.1	17.1	190.5
10	$12.2	$136.6	$ 4.7	$ 70.8	$16.9	$ 207.4
15	11.6	$195.6	$ 4.7	$ 94.3	$16.3	$ 289.9
20	11.1	251.9		117.8	15.8	369.7
25	10.8	306.5		141.3	15.5	447.8
30	10.5	359.5		164.8	15.2	524.3
35	10.3	411.4		188.3	15.0	599.7
40	$10.1	$462.3	$ 4.7	$211.8	$14.8	$674.1

NOTE: (1) Costs for one engine module include: Structures, Engine Installation, Systems Facility, Maintenance and Transportation. The composite learning curve value is 91%. The first unit cost is $16,700,000.

(2) Fixed cost for one engine module include: Propellant and Launch Operations Cost. No learning curve effects were applied in developing these costs.

TABLE 4.2.0.0-IX
TOTAL UNIT AND CUMULATIVE COST
MLLV INJECTION STAGE FUEL MODULE
LESS ENGINES

(DOLLARS IN MILLIONS)

	(1) FUEL MODULE COST		(2) FIXED COST		TOTAL COST	
UNIT	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$7.1	$ 7.1	$4.9	$ 4.9	$12.0	$ 12.0
2	6.5	13.6	4.9	9.8	11.4	23.4
3	6.1	19.7	2.7	12.5	8.8	32.2
4	5.9	25.6		15.2	8.6	40.8
5	5.7	31.3		17.9	8.4	49.2
6	5.6	36.8		20.6	8.3	57.4
7	5.4	42.3		23.3	8.1	65.6
8	5.3	47.6		26.0	8.0	73.6
9	5.3	52.9		28.7	8.0	81.6
10	$5.2	$ 58.1	$2.7	$ 31.4	$ 7.9	$ 89.5
15	$4.9	$ 83.1	$2.7	$ 44.9	$ 7.6	$128.0
20	4.7	107.1		58.4	7.4	165.5
25	4.6	130.3		71.9	7.3	202.2
30	4.5	152.9		85.4	7.2	238.3
35	4.4	174.9		98.9	7.1	273.8
40	4.3	196.6		112.4	7.0	309.0
50	4.2	238.8		139.4	6.9	378.2
60	4.1	279.9		166.4	6.8	446.3
70	4.0	320.1		193.4	6.7	513.5
80	$3.9	$359.5	$2.7	$220.4	$ 6.6	$579.9

NOTE: (1) Costs for one fuel module include: Structures, Engine Installation, Systems Facility, Maintenance and Transportation. The composite learning curve value is 91%. The first unit cost is $7,100,000.

(2) Fixed cost for one fuel module include: Propellant and Launch Operations cost. No learning curve effects were applied in developing these costs.

TABLE 4.2.0.0-X
TOTAL COST
MLLV INJECTION STAGE ENGINES (DOLLARS IN MILLIONS)

	ENGINE COST			ENGINE COST	
UNIT NBR(S)	UNIT OR BLOCK	CUM	UNIT NBR(S)	UNIT OR BLOCK	CUM
2	$2.7	$ 2.7	44	$2.1	$ 49.0
4	2.5	5.2	46	2.1	51.1
6	2.4	7.6	48	2.1	53.2
8	2.4	10.0	50	2.1	55.3
10	2.3	12.3	52	2.0	57.3
12	2.3	14.6	54	2.0	59.3
14	2.3	16.9	56	2.0	61.3
16	2.2	19.1	58	2.0	63.3
18	2.2	21.3	60	2.0	65.3
20	2.2	23.5	70	2.0	75.3
22	2.2	25.7	80	2.0	85.3
24	2.2	27.9	90	2.0	95.1
26	2.2	30.1	100	1.9	104.9
28	2.1	32.2	110	1.9	114.6
30	2.1	34.3	120	1.9	124.3
32	2.1	36.4	130	1.9	133.9
34	2.1	38.5	140	1.9	143.4
36	2.1	40.6	150	1.9	152.9
38	2.1	42.7	180	1.8	181.0
40	2.1	44.8	210	1.8	208.8
42	$2.1	$46.9	240	1.3	$236.4

NOTE: The learning curve value is 95%. The first unit cost of the 125,000 pounds thrust engine is $1,370,000.

TABLE 4.2.0.0-XI
TOTAL COST
MLLV COST FOR THE ALTERNATE FORWARD
SKIRT AND SRM FIXED COSTS

(DOLLARS IN MILLIONS)

FLIGHT UNIT NBR	(1) ALTERNATE FORWARD SKIRT COST		(2) SRM FIXED COST PER FLIGHT		TOTAL COST PER FLIGHT	
	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$2.9	$2.9	$20.6	$20.6	$23.5	$23.5
2	2.6	5.5	20.6	41.2	23.2	46.7
3	2.5	8.0	6.5	47.7	9.0	55.7
4	2.4	10.4		54.2	8.9	64.6
5	2.3	12.8		60.7	8.8	73.5
6	2.3	15.0		67.2	8.8	82.2
7	2.2	17.3		73.7	8.7	91.0
8	2.2	19.5		80.2	8.7	99.7
9	2.2	21.6		86.7	8.7	108.3
10	$2.1	$23.7	$ 6.5	$93.2	$ 8.6	$116.9
15	$2.0	$34.0	$ 6.5	$125.7	$ 8.5	$159.7
20	1.9	43.7		158.2	8.4	201.9
25	1.9	53.2		190.7	8.4	243.9
30	1.8	62.4		223.2	8.3	285.6
35	1.8	71.4		255.7	8.3	327.1
40	$1.8	$80.3	$ 6.5	$288.2	$ 8.3	$368.5

NOTE: (1) Costs associated with the alternate forward skirt are "Delta" costs, over and above those costs required for a standard forward skirt. The composite learning curve value is 91%. The first unit delta cost is $2,900,000.

(2) SRM fixed costs include: Launch Operations and Launch Maintenance cost. No learning curve effects were applied in developing these costs.

TABLE 4.2.0.0-XII
TOTAL COST
MLLV SOLID ROCKET MOTOR STAGE
QUANTITY SENSITIVE COST

(DOLLARS IN MILLIONS)

NBR(S)	UNIT OR BLOCK COST	CUM COST	NBR(S)	UNIT OR BLOCK COST	CUM COST
1-2	$21.0	$ 21.0	44	$16.3	$ 384.1
4	19.6	40.6	46	16.2	400.3
6	19.0	59.6	48	16.2	416.5
8	18.5	78.1	50	16.1	432.6
10	18.2	96.3	52	16.0	448.6
12	17.9	114.2	54	16.0	464.6
14	17.8	132.0	56	$16.0	480.6
16	17.6	149.6			
18	17.4	167.0			
20	17.2	184.2			
22	17.2	201.4	64	15.8	544.1
24	17.0	218.4	72	15.7	607.1
26	16.9	235.3	80	15.6	669.5
28	16.8	252.1	88	15.4	731.4
30	16.8	268.9	96	15.3	793.0
32	16.6	285.5	104	15.2	854.1
34	16.6	302.1	112	15.1	915.0
36	16.5	318.6	120	15.1	975.5
38	16.5	335.1	128	15.0	1,035.7
40	16.4	351.5	144	15.0	$1,155.3
42	$16.3	$367.8			

NOTE: Costs associated with the SRM stage cost include: structures, SRM motor, other stage hardware and facility maintenance. The composite learning curve value is 95%. The first unit cost is $10,754,000.

TABLE 4.2.0.0-XIII

TOTAL UNIT AND CUMULATIVE COST

AMLLV SINGLE STAGE VEHICLE W/MULTICHAMBER/PLUG ENGINES

(DOLLARS IN MILLIONS)

	(1) SINGLE STAGE		(2) MULTICHAMBER PLUG ENGINE (BLOCKS OF 24 EACH)		(3) FIXED COST		TOTAL COST	
UNIT	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$118	$ 118	$71	$ 71	$239	$ 239	$428	$ 428
2	107	225	64	135	238	477	409	837
3	101	326	62	197	130	607	293	1,130
4	97	423	61	258		737	288	1,418
5	94	517	60	318		867	284	1,702
6	92	609	59	377		997	281	1,983
7	90	699	58	435		1,127	278	2,261
8	89	788	57	492		1,257	276	2,537
9	87	875	57	549		1,387	274	2,811
10	86	961	56	605	130	1,517	272	3,083
15	81	1,376	54	879	130	2,167	265	4,422
20	78	1,773	53	1,148		2,817	261	5,738
25	76	2,156	52	1,412		3,467	258	7,035
30	74	2,530	52	1,672		4,117	256	8,319
35	72	2,895	51	1,928		4,767	253	9,590
40	$ 71	$3,253	$50	$2,182	$130	$5,417	$251	$10,852

NOTE:

(1) Single stage includes cost of structures, systems, maintenance, transportation and engine installation. The composite curve value is 91%. The first unit cost is $118,000,000.

(2) Multichamber/plug engines are based on an estimated first unit cost of $3,500,000 and a learning curve value of 95%.

(3) Fixed costs for each single stage vehicle include: propellant, IU, SDF operations, launch operations and maintenance and SE&I costs. Units 1 and 2 include R&D instrumentation. No learning curve effects were applied in developing these costs.

TABLE 4.2.0.0-XIV
TOTAL UNIT AND CUMULATIVE COST

AMLLV SINGLE STAGE VEHICLE W/TOROIDAL ENGINES (DOLLARS IN MILLIONS)

	(1) SINGLE STAGE		(2) TOROIDAL ENGINES		(3) FIXED COST		TOTAL COST	
UNIT	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$118	$ 118	$47	$ 47	$239	$239	$404	$404
2	107	225	45	92	238	477	390	794
3	101	326	44	136	130	607	295	1,069
4	97	423	43	179	↑	737	270	1,339
5	94	517	42	221		867	266	1,605
6	92	609	41	262		997	263	1,768
7	90	699	41	303		1,127	261	2,129
8	89	788	41	344		1,257	260	2,389
9	87	875	40	384	↓	1,387	257	2,646
10	86	961	40	424	130	1,517	256	2,902
15	81	1,376	39	619	130	2,167	250	4,162
20	78	1,773	38	810	↑	2,817	246	5,400
25	76	2,156	37	998		3,467	243	6,621
30	74	2,530	37	1,183		4,117	241	7,830
35	72	2,895	36	1,365	↓	4,767	238	9,027
40	$ 71	$ 3,253	$36	$1,546	$130	$5,417	$237	$10,216

NOTE:

(1) Single Stage includes cost of structures, systems, maintenance and transportation and engine installation. The composite curve value is 91%. The first unit cost is $118,000,000.

(2) Toroidal engines are based on an estimated first unit cost of $47,300,000. This consists of a 16 module, 2,000 PSI (1.0m lb thrust per module) engine. The learning curve value is 95%.

(3) Fixed costs for each single stage vehicle include: Propellant, IU, SDF operations, launch operations and maintenance and SE&I costs. No learning curve effects were applied in developing these costs.

TABLE 4.2.0.0-XV
TOTAL UNIT AND CUMULATIVE COST
AMLLV INJECTION STAGE ENGINE MODULE
LESS HIGH PRESSURE ENGINES

(DOLLARS IN MILLIONS)

UNIT	(1) ENGINE MODULE		(2) FIXED COST		(3) TOTAL COST	
	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$20.4	$ 20.4	$17.4	$ 17.4	$37.8	$ 37.8
2	18.6	39.0	17.4	34.8	36.0	73.8
3	17.5	56.5	5.8	40.6	23.3	97.1
4	16.9	73.4		46.4	22.7	119.8
5	16.4	89.9		52.2	22.2	142.0
6	16.0	105.8		58.0	20.8	163.8
7	15.7	121.5		63.8	21.5	185.3
8	15.3	136.8		69.6	21.1	206.4
9	15.2	152.0		75.4	21.0	227.4
10	14.9	166.9	5.8	81.2	20.7	248.1
15	14.1	239.0	5.8	110.2	19.9	349.2
20	13.6	308.0		139.2	19.4	447.2
25	13.2	374.0		163.2	19.0	542.2
30	12.8	439.0		197.2	18.6	636.2
35	12.6	503.0		226.2	18.4	729.2
40	$12.3	$565.0	$ 5.8	$255.2	$18.1	$820.2

NOTE: (1) Costs for one engine module include: Structures, Engine Installation, Systems, Facility Maintenance and Transportation. The composite learning curve value is 91%. The first unit cost is $20,400,000.

(2) Fixed cost for one engine module include: Propellant and Launch Operations cost. No learning curve effects were applied in developing these costs.

(3) Refer to Table 4.2.0.0-XVII for Engine cost.

TABLE 4.2.0.0-XVI
TOTAL UNIT AND CUMULATIVE COST
AMLLV INJECTION STAGE FUEL MODULE
LESS HIGH PRESSURE ENGINES

(DOLLARS IN MILLIONS)

UNIT	(1) FUEL MODULE		(2) FIXED COST		(3) TOTAL COST	
	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	$9.6	$ 9.6	$6.0	$ 6.0	$15.6	$ 15.6
2	8.7	18.3	6.0	12.0	14.7	30.3
3	8.3	26.6	3.3	15.3	11.6	41.9
4	8.0	34.6		18.6	11.3	53.2
5	7.7	42.3		21.9	11.0	64.2
6	7.5	49.8		25.2	10.8	75.0
7	7.4	57.2		28.5	10.7	85.7
8	7.2	64.4		31.8	10.5	96.2
9	7.1	71.5		35.1	10.4	106.6
10	7.0	78.5	3.3	38.4	10.3	116.9
15	6.6	112.4	3.3	54.9	9.9	167.3
20	6.4	144.8		71.4	9.7	216.2
25	6.2	176.2		87.9	9.5	264.1
30	6.0	206.7		104.4	9.3	311.1
35	5.9	236.5		120.9	9.2	357.4
40	5.8	265.8		137.4	9.1	403.2
50	5.6	322.9		170.4	8.9	493.3
60	5.5	378.5		203.4	8.8	581.9
70	5.4	432.8		236.4	8.7	669.2
80	$5.3	$486.1	$3.3	$269.4	$ 8.6	$755.5

NOTE:

(1) Costs for one fuel module include: Structure, Engine Installation, and Systems cost. The composite learning curve value is 91%. The first unit cost is $9,600,000.

(2) Fixed costs include: Propellant and Launch Operations. No learning curve effects were applied in developing these costs.

(3) Refer to Table 4.2.0.0-XVII for Engine cost.

TABLE 4.2.0.0-XVII

TOTAL COST

AMLLV INJECTION STAGE ENGINES

(DOLLARS IN MILLIONS)

UNIT	CUM COST
2	$ 3.8
4	7.4
6	10.9
8	14.2
10	17.6
12	20.8
14	24.1
16	27.3
18	30.4
20	33.6
22	36.7
24	39.8
26	42.9
28	46.0
30	49.0
32	52.0
34	55.1
36	58.1
38	61.1
40	$64.1

UNIT	CUM COST
42	$ 67.0
44	70.0
46	73.0
48	75.9
50	78.8
52	81.8
54	84.7
56	87.6
58	90.5
60	93.4
70	107.8
80	122.0
90	136.1
120	177.8
150	218.7
180	259.0
210	298.8
240	$338.2

NOTE: The learning curve value is 95%. The first unit cost of the 250,000 pound thrust engine is $1,960,000.

TABLE 4.2.0.0-XVIII
TOTAL CUMULATIVE COST
AMLLV SRM COST - FIXED AND VARIABLE

(DOLLARS IN MILLIONS)

(1) SRM STAGE COST					
UNIT	UNIT	CUM	UNIT	UNIT	CUM
2	25.4	$ 25.4	42	19.8	$ 446.4
4	23.9	49.3	44	19.8	446.2
6	23.0	72.3	46	19.6	485.8
8	22.5	94.8	48	19.6	505.4
10	22.1	116.9	50	19.6	525.0
12	21.8	138.7	52	19.5	544.5
14	21.5	160.2	54	19.4	563.9
16	21.3	181.5	56	19.4	583.3
18	21.1	202.6	58	19.4	602.7
20	21.0	223.6	60	19.3	622.0
22	20.8	244.4			
24	20.7	265.1	120	18.3	1,183.9
26	20.5	285.6	180	17.8	1,724.6
28	20.4	306.0	240	17.4	2,251.8
30	20.3	326.3	300	17.1	2,769.3
32	20.3	346.6	360	16.9	3,279.2
34	20.1	366.7	420	16.7	3,782.8
36	20.1	386.7	480	16.5	4,281.1
38	20.1	406.7			
40	19.9	$426.6			

	(2) ΔCOST FOR ALTERNATE FWD SKIRT		(3) FIXED COST PER LAUNCH (SRM)		TOTAL SKIRT + FIXED	
UNIT	UNIT	CUM	UNIT	CUM	UNIT	CUM
1	4.6	$ 4.6	27.4	$ 27.4	32.0	$ 32.0
2	4.2	8.8	27.4	54.8	31.6	63.6
3	4.0	12.8	7.9	62.7	11.9	75.5
4	3.9	16.7		70.6	11.8	87.3
5	3.7	20.4		78.5	11.6	98.9
6	3.6	24.0		86.4	11.5	110.4
7	3.6	27.6		94.3	11.5	121.9
8	3.5	31.1		102.2	11.4	133.3
9	3.4	34.5		110.1	11.3	144.6
10	3.4	37.9	7.9	118.0	11.3	155.9
15	16.3	54.2	7.9	157.5	24.2	211.7
20	15.6	69.8		197.0	23.5	266.8
25	15.2	85.0		236.5	23.1	321.5
30	14.7	99.7		276.0	22.6	375.7
35	14.4	114.1		315.5	22.3	429.6
40	14.1	$128.2	7.9	355.0	22.0	$483.2

NOTE:
(1) Costs associated with the SRM stage cost include: Structures, SRM Motor, other stage hardware, and Facility Maintenance. The composite learning curve is 95%. The first unit cost is $13,050,000.
(2) Delta costs associated with the alternate forward skirt include all production costs over and above that of a standard forward skirt. The composite learning curve is 91%. The first unit cost is $4,600,000.
(3) SRM fixed costs include Launch Operations and Launch Maintenance. No learning curve effects were applied in developing these costs.

4.3 METHODS FOR DETERMINING UNIT COSTS AND FOR COMPILING OVERALL PROGRAM COSTS

This section presents examples showing the use of the learning curve tables, provided in Section 4.2, to determine: (1) the operational cost of a tenth AMLLV representative vehicle configuration and (2) the overall program costs for a sample program consisting of a mix of AMLLV configurations. The overall program costs determined for the latter example include not only the operational costs, but the non-recurring costs also.

The cost of producing and launching a 10th unit AMLLV vehicle consisting of (1) a main stage with multichamber/plug engines, (2) one injection stage engine module, and (3) twelve strap-on stages can be determined as follows:

10th Unit Description	Unit Price		Ref. Table
Main Stage			
Single Stage Vehicle (No. 10)	$ 86.0M		4.2.0.0-XIII
Multichamber/ Plug Engines No.'s 217-240 (Block of 24)	56.0M		4.2.0.0-XIII
Fixed Cost	130.0M		4.2.0.0-XIII
		$271.0M	
Injection Stage Engine Module			
Engine Module (No. 10)	$ 14.9M		4.2.0.0-XV
Fixed Cost	5.8M		4.2.0.0-XV
High Pressure Engines (No.'s 19 and 20)	3.2M		4.2.0.0-XVII
Sub-Total		$ 23.9M	

4.3 (Continued)

10th Unit Description	Unit Price		Ref. Table
Strap-On Stage(s)			
SRM Stage Cost (No.'s 109-120)	$110.3M		4.2.0.0-XVIII
Alternate Fwd. Skt. (No. 10)	3.4M		4.2.0.0-XVIII
Fixed Cost	7.9M		4.2.0.0-XVIII
Sub-Total		$121.6M	
TOTAL COST		$416.5M	

Use of the learning curve tables to determine overall program costs is illustrated considering a twelve vehicle AMLLV program consisting of the following:

I "Get Ready" Phase
II Development Test Phase (exclusive of R&D flight tests)
III Two R&D flight vehicles (Max. payload config) followed by:
IV six single-stage-to-orbit vehicles followed by:
V One maximum payload AMLLV vehicle followed by:
VI Three vehicles consisting of a main stage with four SRM's.

		Cumulative Cost		Ref. Table
I.	"Get Ready, A costs			
	Main Stage	$1325.2M		4.0.0.0-I
	Injection Stage Engine Module	248.1M		4.0.0.0-I
	Two Injection Stage Fuel Modules	1.4M		4.0.0.0-I
	SRM Fixed	311.8M		4.0.0.0-I
	SRM Variable	88.5M		4.0.0.0-I
	Total A Costs		$1,975.0M	

4.3 (Continued)

		Cumulative Cost		Ref. Table
II.	Development Test. B Costs (Exclusive of Two R&D Flight Tests)			
	Main Stage	$1,210.5M		4.0 0 0-II
	Injection Stage Engine Module	337.7M		4.0.0.0-II
	Two Injection Stage Fuel Modules	73.9M		4.0.0.0-II
	SRM Stage	214.1M		4.0.0.0-II
	Total B Costs		$1,836.2M	
III.	Two R&D Flight Vehicles			
	Main Stage			
	Single Stage Vehicle (No.'s 1-2)	$ 225.0M		4.2.0.0-XIII
	Multichamber/ Plug Engines (No.'s 1-48)	135.0M		4.2.0.0-XIII
	Fixed Cost	477.0M		4.2.0.0-XIII
	Sub-Total		$837.0M	
	Injection Stage - Engine Modules			
	Engine Modules (No.'s 1-2)	$39.0M		4.2.0.0-XV
	Fixed Cost	34.8M		4.2.0.0-XV
	125K Thrust Engine (No.'s 1-2 & 7-8)	7.1M		4.2.0.0-XVII
	Sub-Total		$80.9M	

4.3 (Continued)

Two R&D Flight Vehicles	Cumulative Cost		Ref. Table
Injection Stage - Fuel Module			
Fuel Module (No.'s 1-4)	34.6M		4.2.0.0-XVI
Fixed Cost	18.6M		4.2.0.0-XVI
125K Thrust Engine (No.'s 3-6 & 9-12)	13.7M		4.2.0.0-XVII
Sub-Total		$66.9M	
SRM Strap-On Stage			
SRM Stage (No.'s 1-24)	$265.1M		4.2.0.0-XVIII
Alt. Fwd. Skt. (No.'s 1-2)	8.8M		4.2.0.0-XVIII
SRM Fixed Cost	54.8M		4.2.0.0-XVIII
Sub-Total		$328.7M	
TOTAL		$1,313.5M	

IV. Six Single Stage Vehicles	Cumulative Cost		Ref. Table
Main Stage			
Single Stage Vehicle (No.'s 3-8)	$563.0M		4.2.0.0-XIII
Multichamber/Plug (No.'s 49-192)	357.0M		4.2.0.0-XIII
Fixed Cost	780.0M		4.2.0.0-XIII
TOTAL		$1,700.0M	

4.3 (Continued)

V. One Maximum Payload Vehicle	Cumulative Cost		Ref. Table
Main Stage			
Single Stage Vehicle (No. 9)	$ 87.0M		4.2.0.0-XIII
Multichamber/Plug (No.'s 193-216)	57.0M		4.2.0.0-XIII
Fixed Cost	130.0M		4.2.0.0-XIII
Sub-Total		$274.0M	
Injection Stage - Engine Module			
Engine Module (No. 3)	$ 17.5M		4.2.0.0-XV
Fixed Cost	5.8M		4.2.0.0-XV
High Pressure Engines (No.'s 13-14)	3.3M		4.2.0.0-XVII
Sub-Total		$ 26.6M	
Injection Stage - Fuel Modules - (Two)			
Fuel Module (No.'s 5-6)	$15.2M		4.2.0.0-XVI
Fixed Cost	6.6M		4.2.0.0-XVI
High Pressure Engines (No.'s 15-18)	6.3M		4.2.0.0-XVII
Sub-Total		$28.1M	
SRM Strap-On Stage			
SRM Stage (No.'s 25-36)	$121.6M		4.2.0.0-XVIII
Alt. Fwd. Skt. (No. 3)	4.0M		4.2.0.0-XVIII
SRM Fixed Cost	7.9M		4.2.0.0-XVIII
Sub-Total		$133.5M	
TOTAL		$462.2M	

4.3 (Continued)

VI. Three Vehicles Consisting of a Main Stage with Four SRM's	Cumulative Cost		Ref. Table
Main Stage			
Single Stage Vehicle (No.'s 10-12)	$255.0M		4.2.0.0-XIII
Multichamber/Plug Engines (No.'s 217-288)	167.0M		4.2.0.0-XIII
Fixed Cost	390.0M		4.2.0.0-XIII
Sub-Total		$812.0M	
SRM Strap-On Stage			
SRM Stage (No.'s 37-48)	$118.7M		4.2.0.0-XVIII
Alt. Fwd. Skt. (No.'s 4-6)	11.2M		4.2.0.0-XVIII
Fixed Cost	23.7M		4.2.0.0-XVIII
Sub-Total		$153.6M	
TOTAL		$965.6M	

Summary Total Program

I.	"Get Ready", A Costs	$1,975.0M
II.	Development Test, B Costs	1,836.2M
III.	R&D Flight Vehicles	1,313.5M
IV.	Single Stage Vehicle	1,700.0M
V.	Full Size Vehicle	462.2M
VI.	Single Stage W/Four SRM's Each	956.5M
GRAND TOTAL		$8,234.4M

The above representative examples used the multichamber/plug propulsion system on the main stage. The same type of cost data can be developed for vehicles with the toroidal/aerospike propulsion system on the main stage by using the toroidal/aerospike data shown in Table 4.2.0.0-XIV in lieu of the multichamber/plug propulsion data. The MLLV data, contained in Tables 4.2.0.0-VI through 4.2.0.0-XII, may

4.3 (Continued)

be used to develop vehicle cost data and/or vehicle program costs in the same manner as shown above for the AMLLV.

Similar calculations can be performed to determine the costs of larger or smaller size programs for both the AMLLV and the MLLV vehicle configurations as discussed in the following Section 5.1.

5.0 COST EFFECTIVENESS OF PROGRAM AND CONFIGURATION OPTIONS

This section of Volume VI show methods for application of the "modularized" cost data shown in Volumes IV and V (and summarized in the preceding Section 4.0 of this Volume) to evaluate:

1. The overall program costs for specific programs.

2. The effects of program size on overall program costs and cost effectiveness.

3. The relative cost effectiveness of the AMLLV and MLLV sizes as applied to specific program requirements.

4. The cost effectiveness of various AMLLV and MLLV configuration options.

As the number of possible combinations between program and configuration options is significantly large, this section does not attempt to evaluate all of the alternatives. Representative program and configuration trades are presented to demonstrate how such trades can be conducted and how the required input data can be found and applied. These trades also indicate significant trends and the major influencing factors causing these trends.

In all of the cost data presented and discussed, the costs for development production, checkout and launch of the payload are omitted. Similarly, no costs are shown for payload or vehicle operations, such as down range tracking and communications, after vehicle liftoff from the launch pad.

5.1 COST EFFECTIVENESS OF STAGE AND PROGRAM OPTIONS

To show the application of the "modularized" cost data to the evaluation of the overall program cost and cost effectiveness, two different specific program types were defined and costed for both of the vehicle families (the MLLV and the AMLLV families), i.e.;

a. An "unbiased" program - For an unbiased program, the payload size and packaging is assumed to be flexible so it can be adapted to any of the possible vehicle configurations. (Payload size and packaging requirements do not bias the choice of the launch vehicle.) With an unbiased program the manufacturing facilities, test facilities, and the launch complex are sized for the specific vehicle configuration utilized to deliver the payload to orbit.

5.1 (Continued)

b. A "biased" program - For a biased program, any or all of the payload sizes are fixed and, therefore, bias the choice of the launch vehicle. For a biased program, the manufacturing facilities, test facilities and launch complex, therefore, are sized by the maximum size vehicle configuration necessary to deliver the largest specified payload package to orbit.

The resulting data (as discussed and shown below) indicate that the cost effectiveness choices of configurations for a specific program are not only dependent on the total quantity of payload to be launched, but on the bias created by specific fixed payload sizes.

NOTE: For these analyses, a constant production and launch rate of two per year was assumed. Therefore, program duration will vary inversely with vehicle size.

5.1.1 MLLV Unbiased Program Cost Summary

To evaluate the most cost effective combination of MLLV stages for various required total quantities of delivered payload, the total program costs (including all non-recurring costs) for delivering between three million and eighteen million pounds of payload to a 100 NM orbit were determined. The plot of cumulative payload versus total program costs for various MLLV configurations is shown in Figure 5.1.1.0-1.

Each of the seven lines shown on the Figure 5.1.1.0-1 represents one specific vehicle configuration delivering the payload to orbit at a launch rate of two launches per year. The costs were developed based on providing manufacturing, test, launch and other supporting facilities for this manufacturing and launch rate. The specific points shown on each of the lines indicate specific payload increments that can be obtained with each of these configurations.

As shown, seven launches of the MLLV single stage to orbit vehicle are required to deliver three million pounds to a 100 NM orbit. With the same vehicle configuration 39 launches are required to deliver eighteen million pounds to orbit. Two launches of the vehicle configuration consisting of a main stage plus eight SRM stages and a three module injection stage are required to deliver three million pounds. To deliver eighteen million pounds, 10 launches of this larger configuration are required. The figure shows that the most costly ways to deliver the payload to orbit will be with the single stage to orbit vehicle configuration or the vehicle configuration consisting of a main stage plus a single module injection stage. The addition of an injection stage, however, will be a more cost effective option than the use of a single stage to orbit vehicle alone for programs requiring more than nine million pounds. delivered to orbit. Configurations employing the SRM strap-on stages will result

NOTES:

1 PAYLOADS USED ARE FOR VEHICLES WITH THE MULTICHAMBER/PLUG PROPULSION SYSTEM ON THE MAIN STAGE

2 NUMBERS SHOWN TO THE RIGHT OF LETTER INDICATES THE NUMBER OF LAUNCHES NECESSARY TO DELIVER THE PAYLOAD TO ORBIT

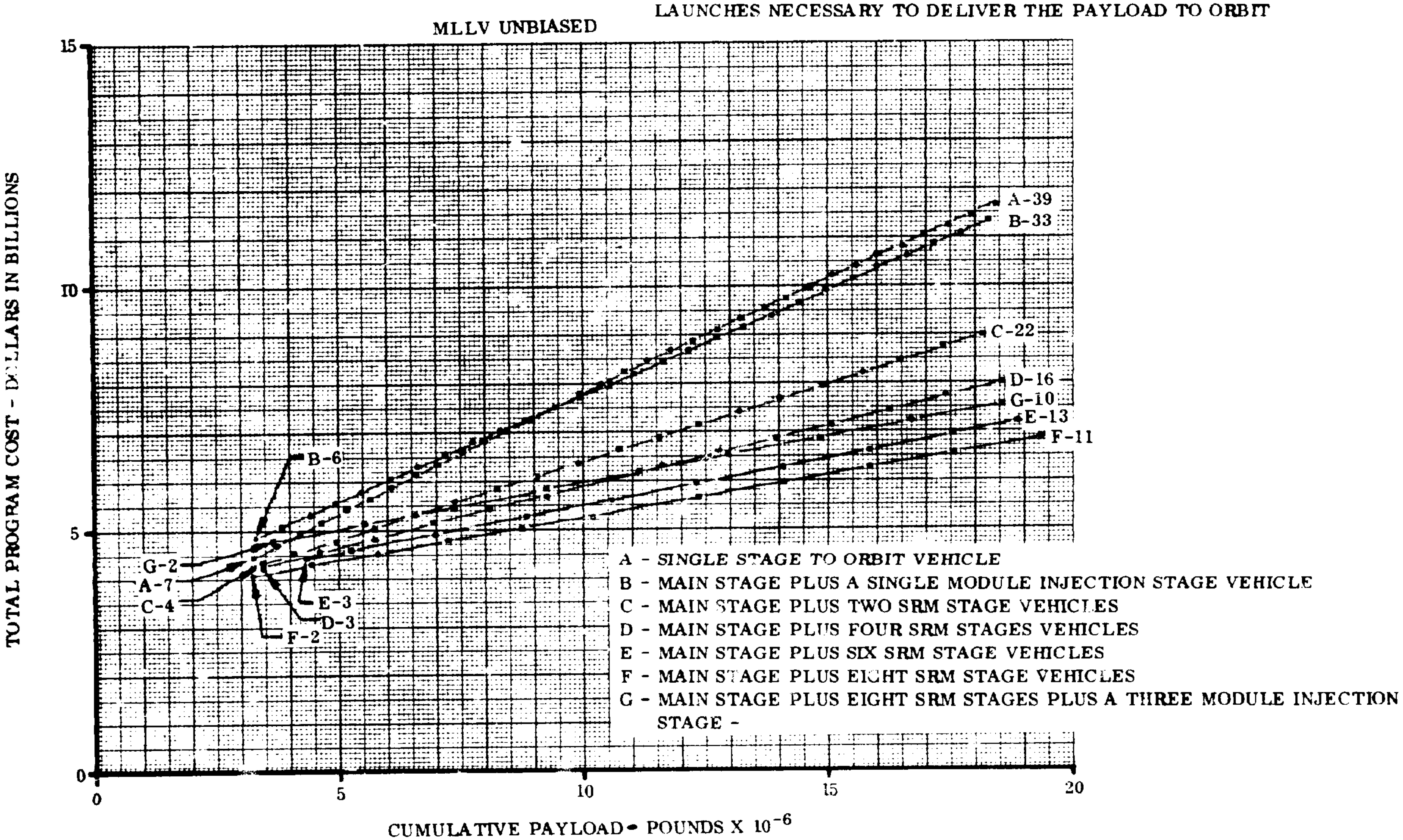


FIGURE 5.1.1.0-1 MLLV UNBIASED PROGRAM COST SUMMARY

FIGURE 5.1.1.0-1 MLLV UNBIASED PROGRAM COST SUMMARY

TABLE 5.1.1.0-1 MLLV UNBIASED PROGRAM COSTS
NO BIAS IN PROGRAM ELEMENTS
(DOLLARS IN THOUSANDS)

ITEM	SINGLE STAGE VEHICLE	MAIN STAGE + INJ. STAGE VEHICLE	MAIN STAGE + 2 SRM's VEHICLE	MAIN STAGE + 4 SRM's VEHICLE	MAIN STAGE + 6 SRM's VEHICLE	MAIN STAGE + 8 SRM's VEHICLE	MAIN STAGE + (3M) INJ. + 8 SRM's VEHICLE
"A" CATEGORY							
MAIN STAGE	$1,104,636	$1,104,636	$1,104,636	$1,104,636	$1,104,636	$1,104,636	$1,104,636
INJECTION STAGE	0	197,740	0	0	0	0	198,450
SOLIDS	0	0	254,051	278,050	303,813	328,441	328,441
"A" TOTAL	$1,104,636	$1,302,376	$1,358,687	$1,382,686	$1,408,449	$1,433,077	$1,631,527
"B" CATEGORY							
MODEL TESTS	$ 600	$ 600	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000
SYSTEMS TEST	120,000	140,000	120,000	120,000	120,000	120,000	140,000
SDF	73,200	80,415	77,775	77,775	77,775	77,775	89,566
MFG. DEV	9,923	11,624	10,041	10,041	10,041	10,041	11,742
ENGINE	325,523	484,994	442,639	442,439	442,639	442,639	602,110
STRUCT. DEV. & TEST	66,420	77,626	75,049	75,049	75,049	75,049	96,845
DTV	53,104	65,104	71,612	71,612	71,612	71,612	97,874
"F" & MOCK-UP	290,712	316,717	320,931	320,931	320,931	320,931	373,162
R&D FLIGHTS	731,826	802,331	819,126	856,626	892,726	928,126	1,048,831
"B" TOTAL	$1,671,308	$1,979,411	$1,938,173	$1,975,673	$2,011,773	$2,047,173	$2,461,130
"C" CATEGORY							
MAIN STAGE	$ 251,300	$ 251,300	$251,300	$251,300	$251,300	$251,300	$251,300
INJECTION STAGE	0	21,400	0	0	0	0	42,600
SOLIDS	0	0	28,000	45,100	61,800	77,800	77,800
1ST OPERATIONAL VEHICLE (THIRD FLIGHT UNIT)	$ 251,300	$ 272,700	$279,300	$296,400	$313,100	$329,100	$371,700
A + B	$2,775,944	$3,281,787	$3,296,860	$3,358,359	$3,420,222	$3,480,250	$4,092,657
C	251,300	272,700	279,300	296,400	313,100	329,100	371,700
A + B + C	$3,027,244	$3,554,487	$3,576,160	$3,654,759	$3,733,322	$3,809,350	$4,464,357
PAYLOADS - VEHICLES WITH:							
MULTICHAMBER/ PLUG WITH SINGLE POSITION NOZZLE ON MAIN STAGE	471,649	553,593	824,478	1,159,489	1,458,179	1,756,869	1,851,441
NUMBER OF LAUNCHES OF VEHICLES WITH MULTICHAMBER/ PLUG SINGLE POSITION NOZZLE ON MAIN STAGE REQUIRED FOR A PROGRAM OF:							
3 MILLION	7	6	4	3	3	2	2
6 MILLION	13	11	8	6	5	4	4
12 MILLION	26	22	15	11	9	7	7
18 MILLION	39	33	22	16	13	11	10
LBS. TO 100 N.M. EARTH ORBIT							

TABLE 5.1.1.0-II MLLV UNBIASED PROGRAM COST SUMMARY

VEHICLE DESCRIPTION PAYLOAD/LAUNCH	NUMBER OF LAUNCHES	TOTAL PAYLOAD	PROGRAM COST ($ IN MILLIONS)
Single Stage	*2 + 7	3,301,543	4,474.3
(471,649 lbs)	2 + 13	6,131,437	5,867.2
	2 + 20	12,262,874	8,863.2
	2 + 39	18,394,311	11,665.8
Main Stage	2 + 6	3,321,558	4,865.9
Plus a Single Module	-	-	-
Injection Stage	-	-	-
(553,593 lbs)	2 + 33	18,268,569	11,459.9
Main Stage	2 + 4	3,297,912	4,389.7
Plus (2) SRM	-	-	-
Stages	-	-	-
(824,478 lbs)	2 + 22	18,138,516	8,992.4
Main Stage	2 + 3	3,478,467	4,233.9
Plus (4) SRM	-	-	-
Stages	-	-	-
(1,159,489 lbs)	2 + 16	18,551,824	7,940.1
Main Stage	2 + 3	4,374,537	4,353.7
Plus (6) SRM	-	-	-
Stages	-	-	-
(1,458,179 lbs)	2 + 13	18,956,327	7,281.5
Main Stage	2 + 2	3,513,738	4,131.5
Plus (8) SRM	-	-	-
Stages	-	-	-
(1,756,869 lbs)	2 + 11	19,325,559	6,910.7
Main Stage	2 + 2	3,702,882	4,825.4
Plus a Three Module	2 + 4	7,405,762	5,540.5
Injection Stage	2 + 7	12,960,087	6,586.8
Plus (8) SRM	2 + 10	18,514,410	7,616.2
Stages			
(1,851,441 lbs)			

*(2) R&D Flights - Do not contribute to total payload

5.1.1 (Continued)

in a lesser number of launches and a lower program costs. (Assuming that the same launch rate can be maintained.) The lowest cost programs (over the payload range investigated) will utilize a vehicle consisting of a main stage plus eight strap-on SRM stages. A review of the cost data showed that the savings in recurring cost accrued for a single launch of such a vehicle will amortize the higher recurring cost required for its implementation. The use of the injection stage is not as cost effective as the use of strap-on SRM stages.

Table 5.1.1.0-I tabulates the data for the seven vehicles used in the unbiased MLLV program cost analysis. Get ready costs, development test costs, and first unit vehicle costs are shown. The payloads for each configuration are identified and the associated number of launches necessary to deliver various quantities of payload are shown.

Table 5.1.1.0-II shows a tabulation of the input data used to prepare Figure 5.1.1.0-1. Included in this table are the total program costs, total payload, and the number of launches necessary to place three million, six million, twelve million, and eighteen million pounds of payload into 100 NM orbit. Shown under the description of each of the vehicles in parenthesis are the payload capability associated with each of the vehicles.

5.1.2 MLLV Biased Program Cost Summary

In the unbiased program option discussed above, costs were determined for vehicles in which the manufacturing, test and launch facilities were specifically sized for a specific vehicle configuration. All of the payloads in the program were delivered by the same configuration. The representative MLLV biased program, discussed in this section, includes the requirement for placing one 1.85 million pound payload package in orbit with a single launch plus additional optional size payload packages. This requires one launch of a maximum payload vehicle configuration (main stage plus eight SRM stages plus a three module injection stage) coupled with launch of other optional vehicle configurations to deliver the remainder of the payload in the program. With this launch vehicle bias included, the total program costs for delivering between three and eighteen million pounds to a 100 NM orbit were determined. Figure 5.1.2.0-1 illustrates the total program costs versus the cumulative payload delivered to a 100 NM orbit for various MLLV configuration launch options.

As shown in Figure 5.1.2.0-1 the most cost effective option is that which consists of one launch of the maximum payload vehicle coupled with the remainder of launches being conducted with vehicles consisting of a main stage plus eight SRM stages. This option is only slightly more cost effective than the option with continuous use of the maximum payload vehicle configuration. The other options will result in considerably more expensive programs. As would be expected, from the previous

NOTES:

1 PAYLOADS USED ARE FOR VEHICLES WITH THE MULTICHAMBER/PLUG PROPULSION SYSTEM ON THE MAIN STAGE

2 ONE MAX PAYLOAD VEHICLE MUST BE ADDED TO NUMBERS SHOWN TO RIGHT OF LETTERS TO SHOW TOTAL NUMBER OF LAUNCHES REQUIRED

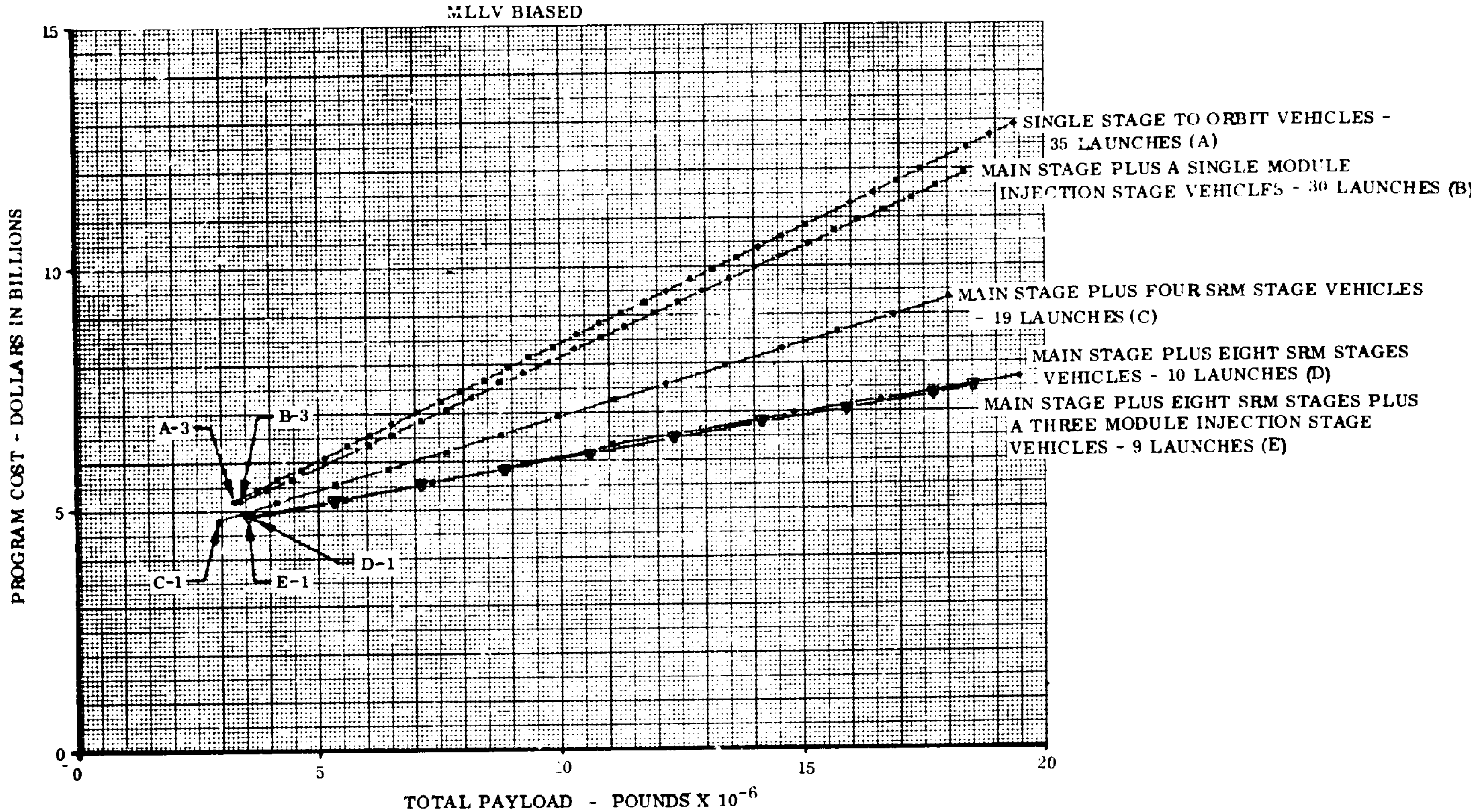


FIGURE 5.1.2.0-1 MLLV BIASED PROGRAM COST SUMMARY

FIGURE 5.1.2.0-1 MLLV BIASED PROGRAM COST SUMMARY

TABLE 5.1.2.0-I   MLLV BIASED PROGRAM COSTS
PROGRAM REQUIRES 2 MAX. SIZE R&D FLIGHTS AND ONE MAX. SIZE OPERATIONAL FLIGHT (DOLLARS IN THOUSANDS)

ITEM	SINGLE STAGE VEHICLE	MAIN STAGE + INJ. STAGE VEHICLE	MAIN STAGE + 2 SRMs VEHICLE	MAIN STAGE + 4 SRMs VEHICLE	MAIN STAGE + 6 SRMs VEHICLE	MAIN STAGE + 8 SRMs VEHICLE	MAIN STAGE + (3M) INJ. STAGE + 8 SRMs VEHICLE
"A" CATEGORY							
MAIN STAGE							1,104,636
INJECTION STAGE							198,450
SOLIDS							328,441
"A" TOTAL	1,631,527						1,631,527
"B" CATEGORY							
"B" TOTAL	2,461,130						2,461,130
"C" CATEGORY							
MAIN STAGE	251,300	251,300	251,300	251,300	251,300	251,300	251,300
INJECTION STAGE	-0-	21,400	-0-	-0-	-0-	-0-	42,600
SOLIDS	-0-	-0-	28,000	45,100	61,800	77,800	77,800
1ST OPERATIONAL VEHICLE (THIRD FLIGHT UNIT)	251,300	272,700	279,300	296,400	313,100	329,100	371,700
A + B	4,092,657	4,092,657	4,092,657	4,092,657	4,092,657	4,092,657	4,092,657
C	251,300	272,700	279,300	296,400	313,100	329,100	371,700
A + B + C	4,343,957	4,365,357	4,371,957	4,389,057	4,405,757	4,421,757	4,464,357
PAYLOAD VEHICLE WITH MULTI-CHAMBER/ PLUG WITH SINGLE POSITION ON MAIN STAGE	471,649	553,593	824,478	1,159,489	1,458,179	1,756,869	1,851,441
NUMBER OF LAUNCHES OF PROGRAM OPTION VEHICLES REQUIRED FOR A PROGRAM OF:							
3M	3	3	2	1	1	1	1
6M	9	8	5	4	3	3	3
12M	22	19	13	9	7	6	6
18M	35	30	20	14	12	10	9
LBS TO 100 N.M. EARTH ORBIT							

TABLE 5.1.2.0-II MLLV BIASED PROGRAM SUMMARY

VEHICLE DESCRIPTION PAYLOAD/LAUNCH	NUMBER OF LAUNCHES	TOTAL PAYLOAD (LBS)	PROGRAM COST ($ IN MILLIONS)
Single Stage (471,649 lbs)	2* + 1** + 3	3,266,388	5,196.4
	2 + 1 + 35	18,359,156	12,445.3
Main Stage Plus a Single Module Injection Stage	2 + 1 + 3	3,452,220	5,257.4
(533,593 lbs)	2 + 1 + 30	18,459,231	11,886.1
Main Stage Plus (4) SRM Stages	2 + 1 + 1	3,010,930	4,752.7
(1,159,489 lbs)	2 + 1 + 14	18,084,287	8,332.9
Main Stage Plus (8) SRM Stages	2 + 1 + 1	3,608,310	4,786.1
(1,756,869 lbs)	2 + 1 + 10	19,420,131	7,567.4
Main Stage Plus	2 + 2	3,702,882	4,827.4
(3) Module Injection	2 + 4	7,405,762	5,542.5
Stage Plus (8)	2 + 7	12,960,087	6,588.8
SRM Stages (1,851,441)	2 + 10	18,514,410	7,614.2

*(2) R&D flights - Do not contribute to total payload

**One payload of the maximum configuration

5.1.2 (Continued)

unbiased program discussion, a single launch of the maximum payload vehicle configuration coupled with the remainder of the launches being conducted with single-stage-to-orbit vehicle configurations is the most expensive program option. The continued use of the injection stage after the launch of the maximum payload vehicle does not appear to be a cost effective option.
Table 5.1.2.0-I lists the input MLLV biased program costs including the "A" get ready costs, the "B" development test costs, and the "C" first unit costs. Since the biased program includes one launch of the maximum payload vehicle configuration, the "A" and the "B" program costs are constant and are the costs for the maximum payload vehicle regardless of what other vehicle configuration options are utilized for the remainder of the launch program. Also shown in this table are the payload capability of the vehicles. It was assumed for all of the vehicle configurations that the main stage would use the multichamber/plug propulsion system with the single position nozzle. The number of launches shown are those launches of the alternative vehicles which must be launched in addition to the maximum vehicle to deliver the payload weights indicated. To obtain the total number of launches in a specific program one maximum payload capability launch plus two R&D flights of the maximum payload vehicle must be added to the number shown.

Table 5.1.2.0-II tabulates the program costs for the costs shown graphically in Figure 5.1.2.0-1.

5.1.3 AMLLV Unbiased Program Cost Summary

To evaluate the most cost effective combination of AMLLV stages for various required total quantities of delivered payload, the total program costs for delivering between six million and thirty-six million pounds of payload to a 100 NM orbit were determined. The plot of cumulative payload versus total program costs for various AMLLV configurations is shown in Figure 5.1.3.0-1.

As was observed with the MLLV unbiased program, the most cost effective vehicle (least program cost to put up total payload) is the configuration consisting of the main stage plus the maximum number of strap-on solid motor stages. The most expensive vehicle programs are those which use either the single stage to orbit vehicle or the main stage plus a single injection stage vehicle. The use of the injection stage does not become cost effective (when compared to the single stage to orbit vehicle) until approximately 28 million pounds are placed into orbit. Then it becomes slightly more effective than delivering the same payload with the single stage to orbit vehicle.

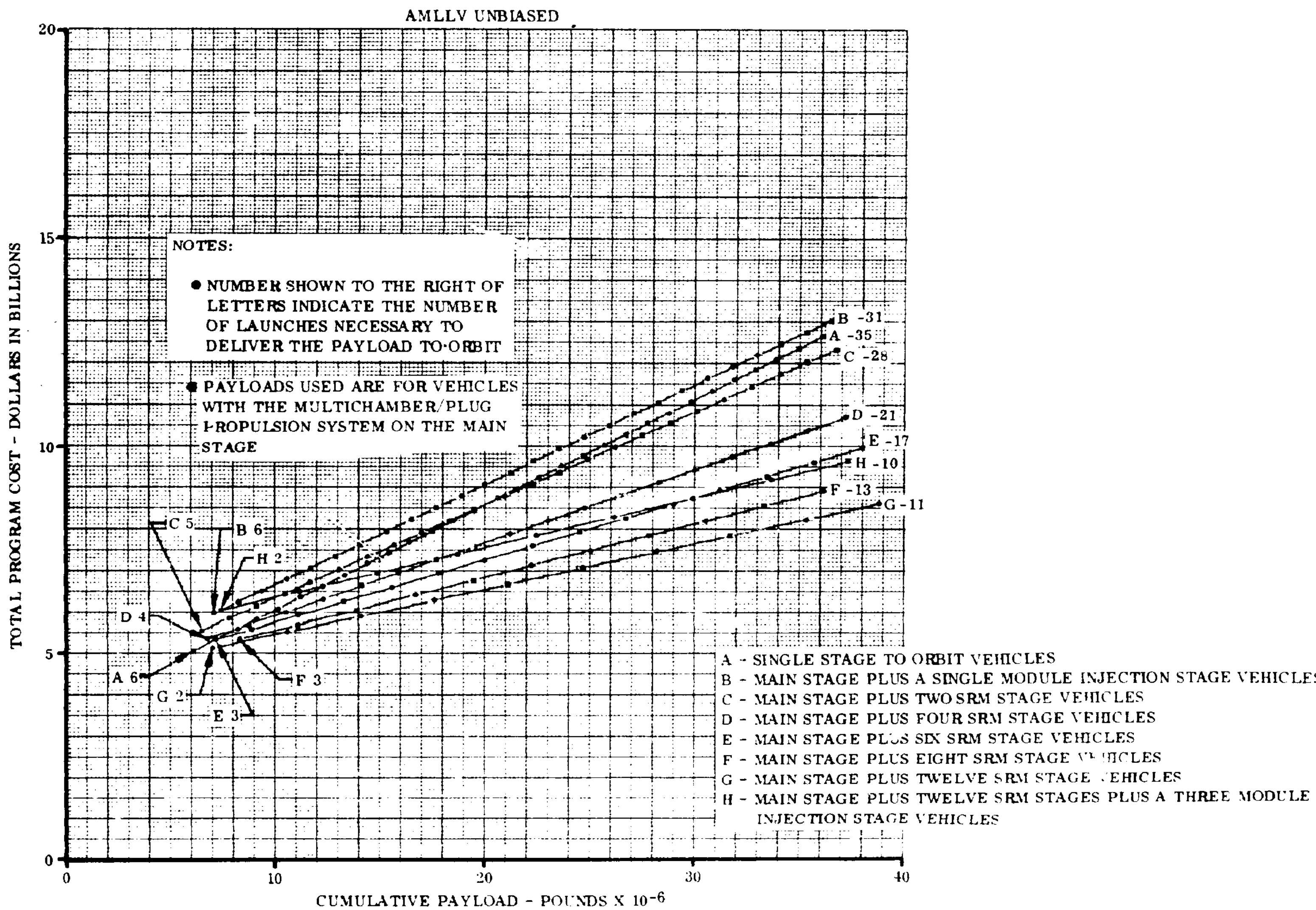


FIGURE 5.1.3.0-1 AMLLV UNBIASED PROGRAM COST SUMMARY

TABLE 5.1.3.0-I AMLLV UNBIASED PROGRAM COSTS (DOLLARS IN THOUSANDS)
NO BIAS IN PROGRAM ELEMENTS

ITEM	SINGLE STAGE VEHICLE	MAIN STAGE + A SINGLE MODULE INJ STAGE VEHICLE	MAIN STAGE + 2 SRM STAGE VEHICLE	MAIN STAGE + 4 SRM STAGE VEHICLE	MAIN STAGE + 6 SRM STAGE VEHICLE	MAIN STAGE + 8 SRM STAGE VEHICLE	MAIN STAGE + 10 SRM STAGE VEHICLE	MAIN STAGE + 12 SRM STAGE VEHICLE	MAIN STAGE + A THREE MODULE INJ STAGE + 12 SRM STAGE VEHICLE
"A" CATEGORY									
MAIN STAGE	1,325,214	1,325,214	1,325,214	1,325,214	1,325,214	1,325,214	1,325,214	1,325,214	1,325,214
INJECTION STAGE	0	248,100	0	0	0	0	0	0	249,520
SOLIDS	0	0	273,941	299,449	324,558	349,695	375,157	400,332	400,332
"A" TOTAL	1,325,214	1,573,314	1,599,155	1,624,663	1,649,772	1,674,909	1,700,371	1,725,546	1,975,066
"B" CATEGORY									
MODEL TESTS	600	600	1,000	1,000	1,000	1,000	1,000	1,000	1,000
SYSTEMS TEST	150,000	175,000	150,000	150,000	150,000	150,000	150,000	150,000	175,000
SDF	80,520	88,457	85,553	85,553	85,553	85,553	85,553	85,553	98,524
MFG. DEV.	9,923	11,624	10,149	10,049	10,049	10,049	10,049	10,049	11,750
ENGINES (AND/OR PFRT)	492,995	733,738	630,763	630,763	630,763	630,763	630,763	630,763	871,506
STRUCT. DEV. & TEST	86,067	101,090	98,254	98,254	98,254	98,254	98,254	98,254	129,261
DTV	66,057	81,795	90,161	90,161	90,161	90,161	90,161	90,161	125,511
"F" & MOCK-UP	324,326	355,924	358,862	358,862	358,862	358,862	358,862	358,862	423,736
R&D FLIGHTS	836,735	918,141	949,635	995,135	1,039,035	1,081,835	1,123,935	1,165,435	1,313,435
"B" TOTAL	2,047,223	2,466,369	2,374,272	2,419,777	2,463,677	2,506,477	2,548,577	2,590,077	3,149,723
"C" CATEGORY									
MAIN STAGE	293,000	293,000	293,000	293,000	293,000	293,000	293,000	293,000	293,000
INJECTION STAGE	0	26,800	0	0	0	0	0	0	54,700
SOLIDS	0	0	38,900	59,800	79,800	99,500	118,600	137,500	137,500
1ST OPERATIONAL VEHICLE (THIRD FLIGHT UNIT)	293,000	319,800	331,900	352,800	372,800	392,500	411,600	430,500	485,200
NON-RECURRING "A" + "B"	3,372,437	4,039,683	3,973,432	4,044,440	4,113,449	4,181,386	4,248,948	4,315,623	5,124,789
RECURRING "C" (ABOVE)	293,000	319,800	331,900	352,800	372,800	392,500	411,600	430,500	485,200
"A" + "B" + "C"	3,665,437	4,359,483	4,305,332	4,397,240	4,486,249	4,573,886	4,660,548	4,746,123	5,609,989
PAYLOAD									
VEHICLE WITH MULTICHAMBER/PLUG ON MAIN STAGE	1,028,887	1,178,356	1,310,000	1,770,000	2,230,000	2,780,000	3,180,000	3,527,290	3,737,738
VEHICLE WITH 2000 PSIA TOROIDAL/AEROSPIKE	980,652								
NUMBER OF LAUNCHES OF A VEHICLE WITH A MULTICHAMBER/PLUG SINGLE POSITION NOZZLE ON THE MAIN STAGE REQUIRED FOR A PROGRAM OF:									
6M	6	6	5	4	3	3	2	2	2
12M	12	10	11	7	6	5	4	4	4
24M	24	21	19	14	11	9	8	7	7
36M	35	31	28	21	17	13	12	11	10
LBS TO EARTH ORBIT									

TABLE 5.1.3.0-II AMLLV UNBIASED PROGRAM SUMMARY

VEHICLE DESCRIPTION PAYLOAD/LAUNCH	NUMBER OF LAUNCHES	TOTAL PAYLOAD	PROGRAM COST ($ IN MILLIONS)
Single Stage	* 2 + 6	6,173,322	5,072.7
(1,028,887)	2 + 35	36,011,045	12,631.8
Main Stage Plus a Single Module Injection Stage	2 + 6	7,070,136	5,892.2
(1,178,356)	2 + 31	36,529,036	12,998.6
Main Stage Plus (2) SRM Stages	2 + 5	6,550,000	5,566.6
(1,310,000)	2 + 28	36,680,000	12,340.2
Main Stage Plus (4) SRM Stages	2 + 4	7,080,000	5,407.6
(1,770,000)	2 + 21	37,170,000	10,830.4
Main Stage Plus (6) SRM Stages	2 + 3	6,690,000	5,201.3
(2,230,000)	2 + 17	37,910,000	9,922.2
Main Stage Plus (8) SRM Stages	2 + 3	8,340,000	5,327.1
(2,780,000)	2 + 13	36,140,000	8,916.9
Main Stage Plus (12) SRM Stages	2 + 2	7,054,580	5,159.6
(3,527,290)	2 + 11	38,800,190	8,750.6
Main Stage Plus a Three module Injection Stage Plus (12)	2 + 2	7,475,476	6,077.8
SRM Stages (3,740,000)	2 + 10	37,377,380	9,667.7

*(2) R&D flights - Do not contribute to total payload

5.1.3 (Continued)

Table 5.1.3.0-I presents the AMLLV unbiased program costs. Shown on this table are nine vehicle configurations and the costs associated with the get ready, development test and first unit costs. The payload capabilities of each vehicle are shown. The main stage contains a multichamber/plug propulsion system with a single position nozzle. The total number of launches required for the range of program sizes is also shown.

Table 5.1.3.0-II shows the program costs for the six million pound payload program and for the 36 million pound payload program for the nine vehicle configurations. The number of launches and the total payload placed into orbit by each of these configurations is also shown on this table. Two launches were included for the R&D flight test. The payload that could be delivered by these R&D flight test vehicles was not included in the total payload capability shown.

5.1.4 AMLLV Biased Program Cost Summary

The representative AMLLV biased program, discussed in this section, includes the requirement for placing a singular 3.7 million pound payload package in orbit with a single launch. This requires one launch of a maximum payload configuration vehicle configuration coupled with launch of other optional vehicle configurations to deliver the remainder of the payload in the program. With this launch vehicle bias included, the total program costs for delivering between six and thirty-six million pounds to a 100 NM orbit were determined. Figure 5.1.4.0-1 illustrates the total program costs versus the cumulative payload delivered to a 100 NM orbit for various MLLV configuration launch options.

As shown in Figure 5.1.4.0-1, the lowest program cost option for the AMLLV biased program is the use of a vehicle consisting of a main stage plus 12 strap-on solid stages. Because of the program bias, the use of an injection stage is always more cost effective when compared to use of a single stage to orbit vehicle. In all instances, use of the vehicles without strap-on stages is considerably more expensive than use of those vehicle configurations utilizing strap-on SRM stages. Use of injection stages with vehicles having strap-on SRM stages will slightly increase program costs.

Table 5.1.4.0-I shows the AMLLV biased program cost summary (with a multichamber/plug engine system on the main stage). As the manufacturing test and launch facilities must be sized for the maximum vehicle configuration, the get ready cost and the development test cost are a constant (fixed) cost for any of the nine vehicle

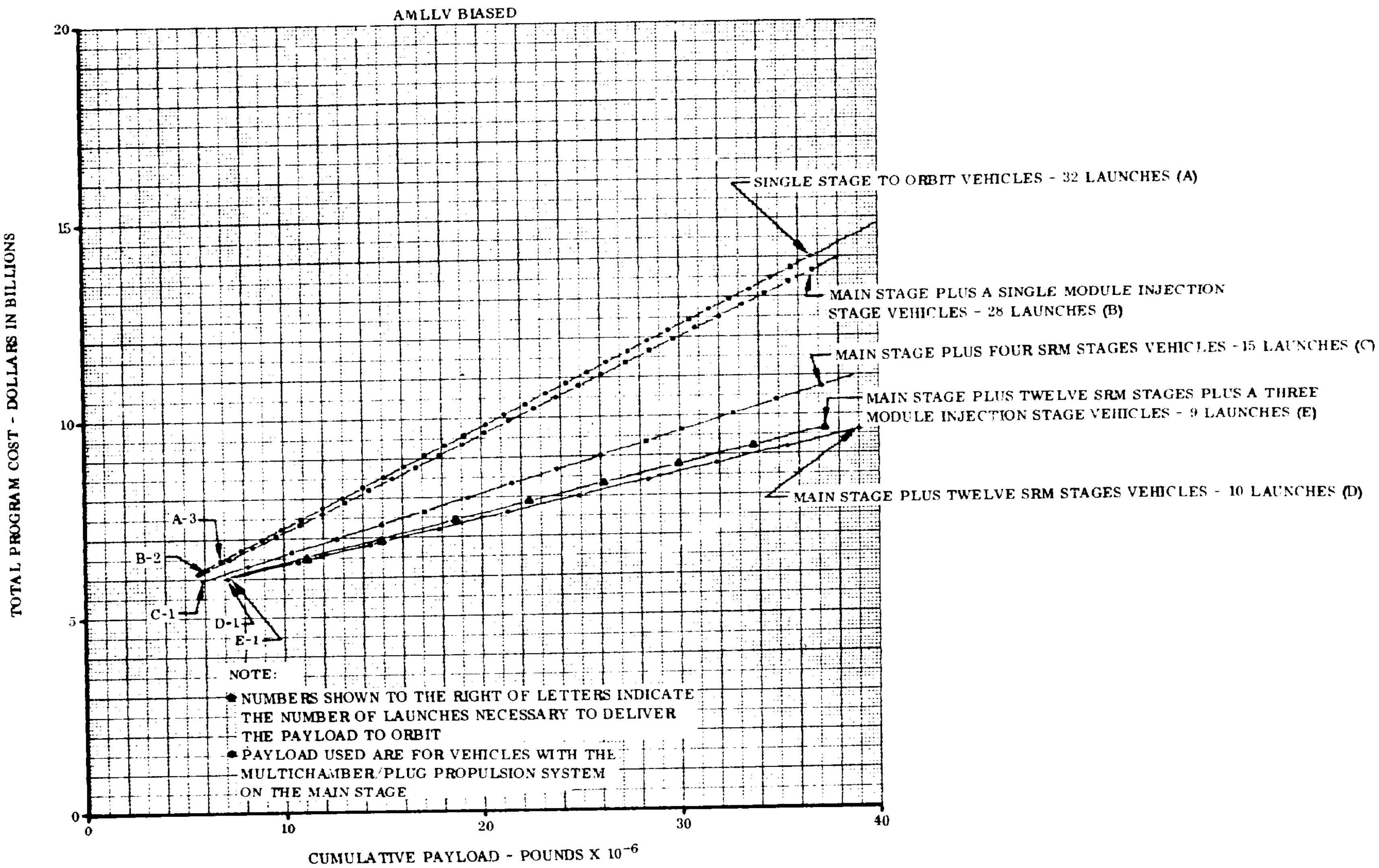


FIGURE 5.1.4.0-1 AMLLV BIASED PROGRAM COST SUMMARY

TABLE 5.1.4.0-I AMLLV BIASED PROGRAM COSTS
PROGRAM REQUIRES 2 MAX. SIZE ?D FLIGHTS AND ONE MAX. SIZE OPERATIONAL FLIGHT
(DOLLARS IN THOUSANDS)

ITEM	SINGLE STAGE VEHICLE	MAIN STAGE + A SINGLE MODULE INJECTION STAGE VEHICLE	MAIN STAGE + 2 SRM STAGE VEHICLES	MAIN STAGE + 4 SRM STAGE VEHICLE	MAIN STAGE + 6 SRM STAGE VEHICLE	MAIN STAGE + 8 SRM STAGE VEHICLE	MAIN STAGE + 10 SRM STAGE VEHICLE	MAIN STAGE + 12 SRM STAGE VEHICLE	MAIN STAGE + A THREE MODULE INJECTION STAGE + 12 SRM STAGE VEHICLE
"A" CATEGORY									
MAIN STAGE									1,325,214
INJECTION STAGE									249,520
SOLIDS									40[illegible],332
"A" TOTAL	1,975,066								1,975,066
"B" CATEGORY									
MODEL TESTS									1,000
SYSTEMS TEST									175,000
SDF									98,524
MFG. DEV.									11,750
ENGINES (OR PFRT)									871,506
STRUCT. DEV. & TEST									129,261
DTV									125,511
"F" & MOCK-UP									423,736
R&D FLIGHTS									1,313,435
"B" TOTAL	3,149,723								3,149,723
"C" CATEGORY									
MAIN STAGE	293,000	293,000	293,000	293,000	293,000	293,000	293,000	293,000	293,000
INJECTION STAGE		26,800							54,700
SOLIDS			38,900	59,800	79,800	99,500	118,600	137,500	137,500
1ST OPERATIONAL VEHICLE (THIRD FLIGHT UNIT)	293,000	319,800	331,900	352,800	371,800	392,500	411,600	430,500	485,200
A + B	5,103,989	5,103,989	5,103,989	5,103,989	5,103,989	5,103,989	5,103,989	5,103,989	5,124,789
C	243,000	319,800	331,900	352,800	371,800	392,500	411,600	430,500	485,200
A + B + C	5,396,989	5,423,789	5,435,889	5,456,789	5,475,789	5,496,489	5,515,589	5,534,489	5,609,989
PAYLOADS									
VEHICLE WITH MULTICHAMBER/ PLUG ON MAIN STAGE	1,028,887	1,178,356	1,310,000	1,770,000	2,230,000	2,780,000	3,180,000	3,527,290	3,737,738
VEHICLE WITH TOROIDAL AEROSPIKE ON MAIN STAGE	980,652								
NUMBER OF LAUNCHES OF VEHICLES WITH MULTICHAMBER/PLUG PROPULSION SYSTEM ON MAIN STAGE REQUIRED FOR A PROGRAM OF									
6M	3	2	2	2	2	1	1	1	1
12M	8	7	7	5	4	3	3	3	3
24M	20	18	16	12	10	8	7	6	6
36M	32	28	25	19	15	12	11	9	9
LBS TO EARTH ORBIT									

TABLE 5.1.4.0-II AMLLV BIASED PROGRAM SUMMARY

VEHICLE DESCRIPTION PAYLOAD/LAUNCH	NUMBER OF LAUNCHES	TOTAL PAYLOAD	PROGRAM COST ($ IN MILLIONS)
Single Stage (1,028,878 lbs)	2** + 1* + 3	6,824,399	6,459.0
	2 + 1 + 32	36,662,122	14,066.0
Main Stage Plus a Single Injection Stage	2 + 1 + 2	6,094,450	6,229.2
(1,178,356 lbs)	2 + 1 + 28	36,731,706	13,690.6
Main Stage Plus (6) SRM Stages	2 + 1 + 1	5,967,738	5,965.5
(2,230,000 lbs)	2 + 1 + 15	37,187,738	10,705.1
Main Stage Plus (12) SRM Stages	2 + 1 + 1	7,265,028	6,024.5
(3,527,290 lbs)	2 + 1 + 10	39,010,638	9,605.1
Main Stage Plus a Three Module Injection Stage + (12) SRM Stages	2 + 2	7,475,476	6,077.8
(3,740,000 lbs)	2 + 10	37,377,380	9,668.7

*One payload of the largest configuration required

**(2) R&D flights of the largest configuration - does not contribute to total payload

5.1.4 (Continued)

configurations shown. Only the production first unit cost varies with the vehicle configuration. Shown in this table are the payload capabilities of the vehicle with the multichamber/plug propulsion system with the single position nozzle on the first stage. Also shown on this chart are the number of launches required to deliver the six million, 12 million, 24 million, and 36 million pounds of payload to 100 NM orbit. The number of launches required as shown are the number of launches required of the vehicle options in addition to the two R&D flight tests of the maximum size vehicle configuration plus one operational launch of a maximum size vehicle.

Table 5.1.4.0-II presents the payload and program cost tabulations for the five vehicle configuration options presented in Figure 5.1.4.0-1. Note that no useful payload was considered from the two R&D flights.

5.1.5 Configuration Influence on Program Cost

This section summarizes the MLLV and AMLLV program cost data shown in the previous sections 5.1.1.0 through 5.1.4.0 to illustrate the effects of configuration selection on overall program cost. Figure 5.1.5.0-1 shows the total program cost for a representative program considering utilization of all of the AMLLV and MLLV vehicle configurations. The representative program shown includes development, implementation and operation of sufficient vehicles to deliver 20,000,000 pounds to a 100 N.M. earth orbit. All non-recurring and recurring program cost were included and there was no restriction on the sizes of the individual payloads. This figure shows that as the payload capability of the vehicle increases that the total program costs will generally decrease. For the size program shown, the maximum payload capability MLLV vehicle, however, is almost as cost effective as the maximum payload capability AMLLV vehicle and is more cost effective than the majority of the AMLLV configurations. As discussed earlier and shown on this figure, the use of the injection stage (as a propulsion unit to achieve orbit) is generally not cost effective. Similar analyses of other program sizes also showed that the use of the injection stage would never be the most cost effective option. For this reason, use of the injection stage, as a propulsive stage to achieve a 100 N.M. earth orbit, was no longer considered and excluded from further cost trades. The injection stage will be a useful stage for use in orbit and for missions beyond a 100 N.M. earth orbit. The injection stage should, therefore, be considered as part of the payload package rather than as part of the orbital injection vehicle.

The trends discussed above were biased by the size of the selected operational program relative to amortization of the non-recurring costs. Figure 5.1.5.0-2 shows the same type data for an operational program only (non-recurring cost excluded). This figure not only confirms the trends discussed above but leads to

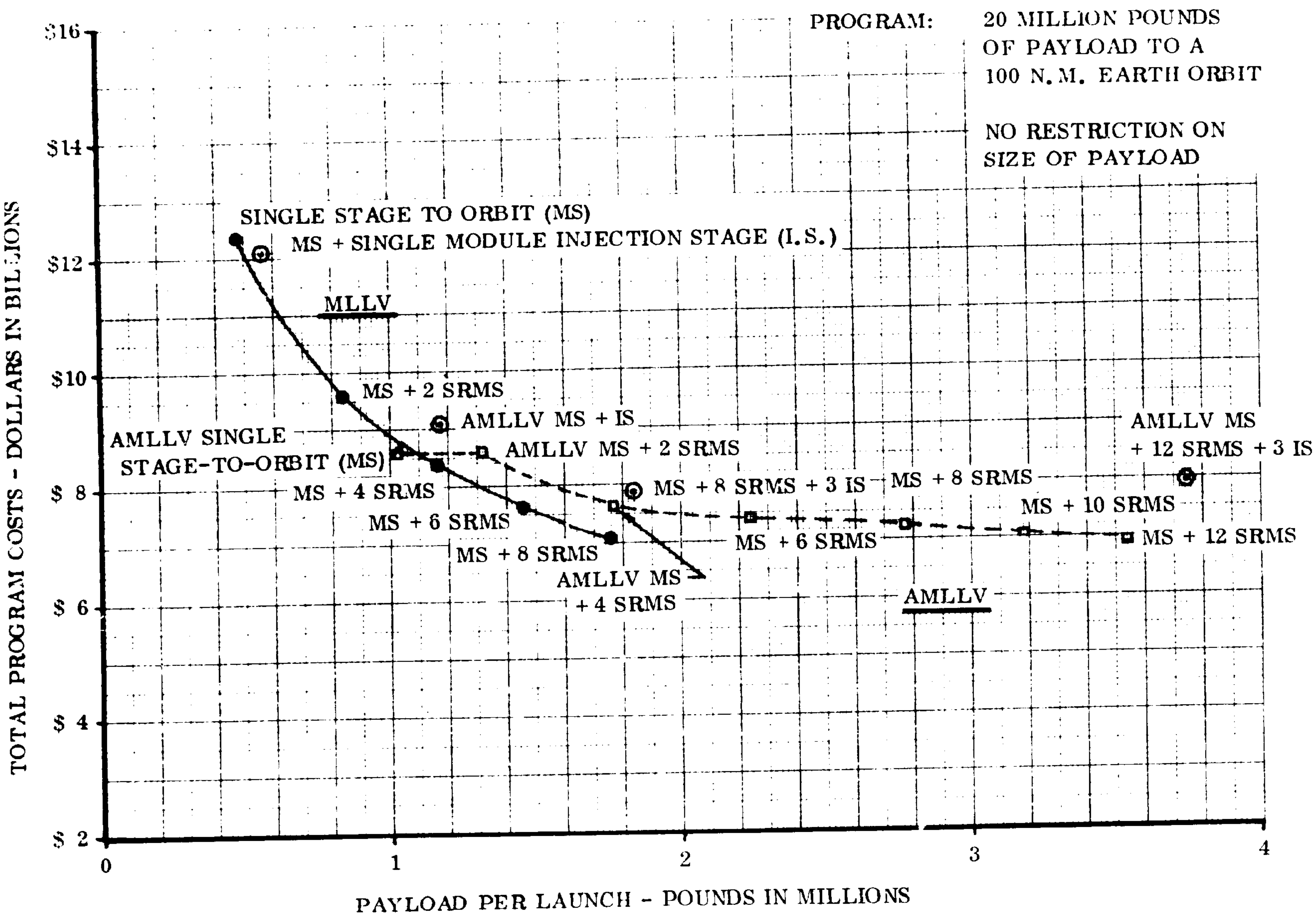


FIGURE 5.1.5.0-1 TOTAL PROGRAM COST VERSUS VEHICLE CONFIGURATION FOR UNBIASED PROGRAM

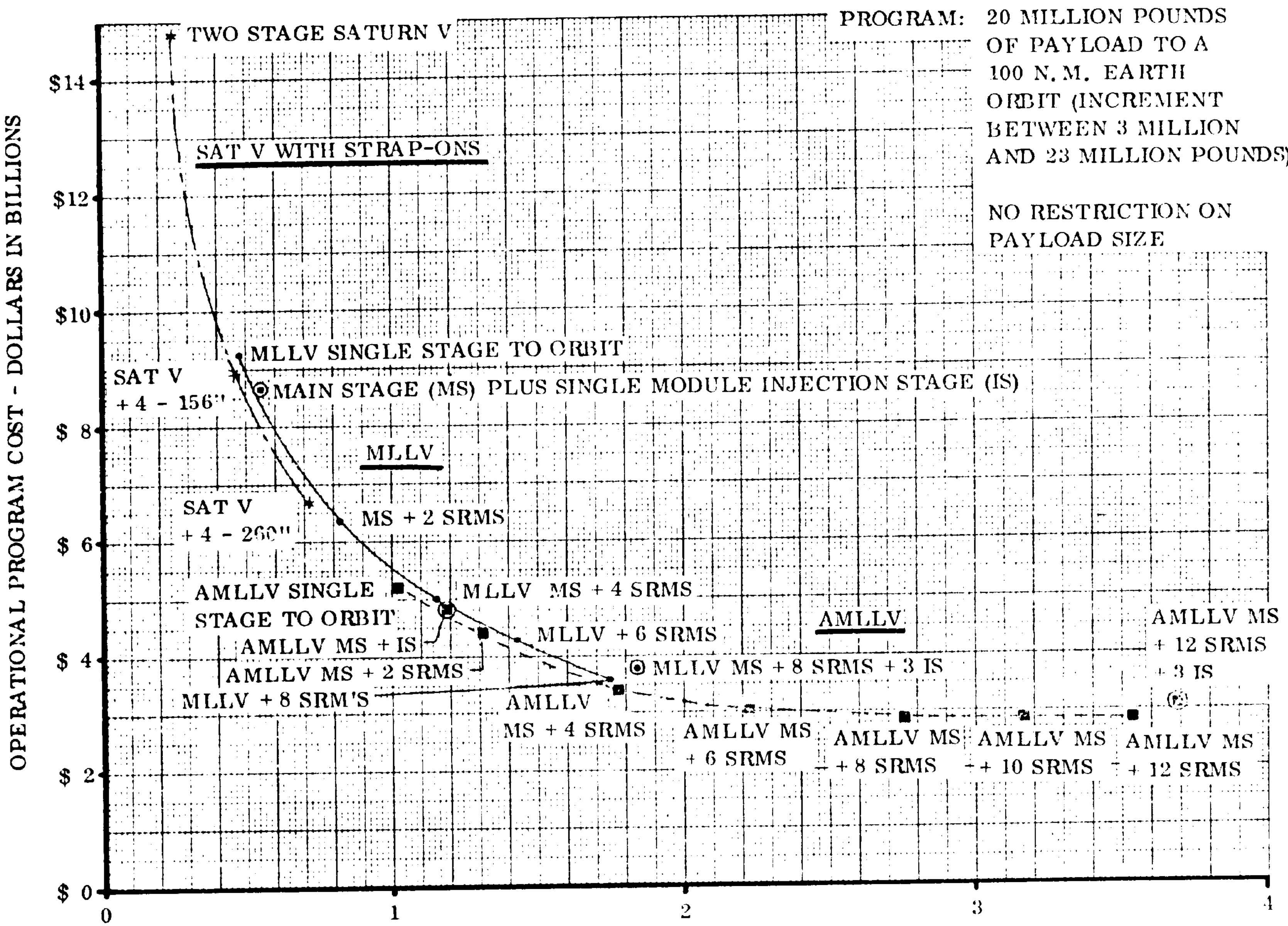


FIGURE 5.1.5.0-2 OPERATIONAL PROGRAM COST VERSUS VEHICLE CONFIGURATION FOR UNBIASED PROGRAM

5.1.5 (Continued)

a significant conclusion, i.e.: for a given payload per launch requirement, recurring costs will not be significantly influenced by the choice of the launch vehicle configuration. For example, for a payload size requirement of approximately 1.8 million pounds per launch, either the MLLV main stage plus 8 strap-on stage vehicle or the AMLLV main stage plus 4 strap-on stage vehicle can be used for basically the same operational cost. Similarly, for a payload size requirement of approximately 1.2 million pounds, an MLLV main stage plus 4 strap-on stages vehicle or an AMLLV main stage plus injection stage vehicle can be used with no significant difference in operational program cost. To further confirm this effect, existing cost data for two stage Saturn V vehicles and for two stage Saturn V vehicles with either 4-156 inch or 4-260 inch diameter SRM strap-ons were normalized for a production and launch rate of two per year. This data, which are also shown in Figure 5.1.5.0-2, further indicate that for a specific payload per launch requirement, costs will be insensitive to configuration selection. For example, for a payload per launch requirement of 500,000 pounds, the MLLV single-stage-to-orbit vehicle or the Saturn V vehicle with four 156 inch SRM strap-ons can be used without a significant difference in cost.

As discussed above, for a given fixed payload per launch requirement, operational program costs will be insensitive to the choice of the launch vehicle configuration. A specific amount of energy, in whatever package, will cost the same amount. This conclusion assumes that all possible configurations will be produced and operated within the same program philosophy, limitations and ground rules.

The data in Figure 5.1.5.0-2 further shows that for increased payload per launch requirements, program cost will decrease. In other words, there appears to be a "quantity discount" relative to size of the payload package. This "quantity discount" is based on the assumption that, whatever size vehicle is used, a production and launch rate of two vehicles per year can be maintained. The effect of this assumption on the "quantity discount" trend is further discussed in Section 5.1.6.

5.1.6 Rate Influence on Unit Cost

The cost effectiveness trades discussed in the preceding sections were accomplished assuming a production and launch rate of two vehicles per year. Prior experience with the Saturn V and other programs has shown that the cost of a launch vehicle is significantly effected by the production and launch rate. This launch rate/cost relationship is such that it could invalidate the trends indicated. The range of size of the vehicles considered is such that a common launch rate may not be applicable. If payload development time is a limiting factor, a program to launch a given weight of payload may require a minimum time for accomplishment. For example, a program to launch 20 million pounds of payload could require a minimum of ten years for accomplishment (two million pounds per year). This rate

5.1.6 (Continued)

limitation on payload would impose the following vehicle production and launch rates:

MLLV Single-Stage-To-Orbit	4.28 launches/yr
MLLV Main Stage Plus Eight Strap-Ons	1.14 launches/yr
AMLLV Single-Stage-To-Orbit	1.94 launches/yr
AMLLV Main Stage Plus Twelve Strap-Ons	0.57 launches/yr

If the unit costs for launch vehicles will be a function of the production and launch rate, a payload limitation on rate will reduce the costs of the smaller vehicles and increase the costs of the larger vehicles. To quantitatively evaluate the rate effect on unit cost, the following activities were accomplished:

a. A review of the rate/unit cost sensitivity of Saturn V/S-IC costs as defined by the Chrysler National Space Booster Study, Contract NASW-1740 (1968) and by additional Boeing in-house studies.

b. A review of the AMLLV/MLLV cost data to define the rate sensitive cost elements.

These reviews resulted in the data shown in Figure 5.1.6.0-1 and 5.1.6.0-2. Figure 5.1.6.0-1 shows cumulative annual recurring program costs as a function of launch rate. This data plus similar non-recurring cost data curves are shown on Figure 5.1.6.0-2. These latter curves show that the unit costs of the AMLLV/MLLV vehicles will be strongly influenced by the production launch rate and show the appropriate factors to be applied to the individual vehicle costs to account for variations in the launch rate from the nominal of two per year.

Figure 5.1.6.0-3 shows how application of these launch rate cost bias factors would effect the results of the program and configuration cost effectiveness studies shown on the preceding Figure 5.1.5.0-2. This figure proposes another significant study conclusion, i.e.: choice of vehicle configuration for any size payload per launch requirement will not significantly effect program costs. The rate bias on costs, as shown on this figure, neutralizes the indicated reduced costs for the larger payload vehicles (neutralizes the "quantity discount" effect). Figure 5.1.6.0-4 shows a matrix of operational costs versus vehicle size (payload per launch) as a function of either various fixed launch rates or variable fixed rates of payload launched per year. This data shows that the above conclusion basically holds for any required quantity of payload per year. There are, however, some minor cost advantages for selection of specific size vehicles for specific payload per year requirements. For example: for a payload per year requirement of 2.0 million pounds, the least expensive vehicle would be that configuration with approximately 2 million pounds of payload capability. Choice of either larger or smaller vehicles would tend to increase the operational program costs. Similarly,

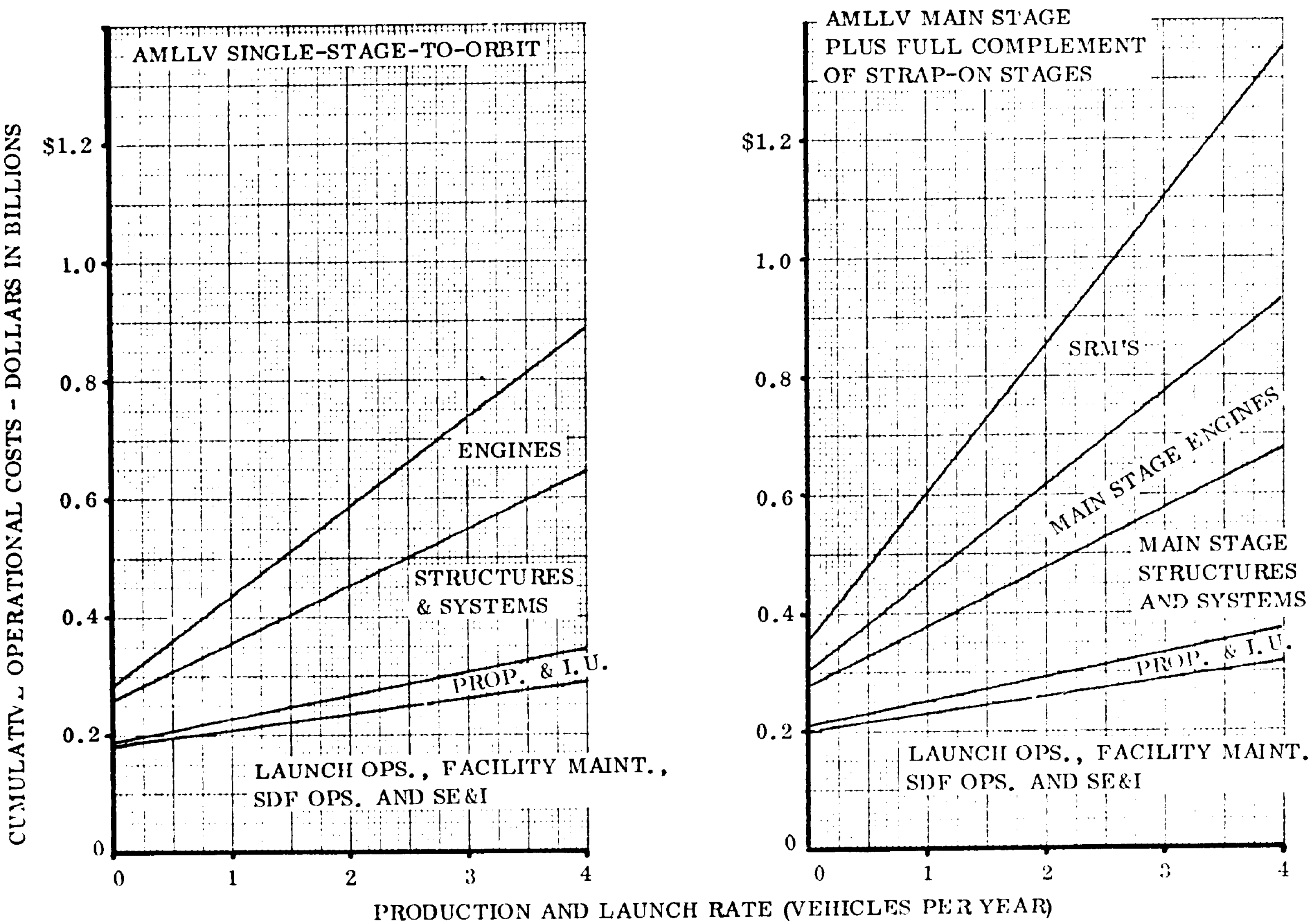


FIGURE 5.1.6.0-1 ANNUAL OPERATING COSTS AS A FUNCTION OF THE PRODUCTION AND LAUNCH RATE

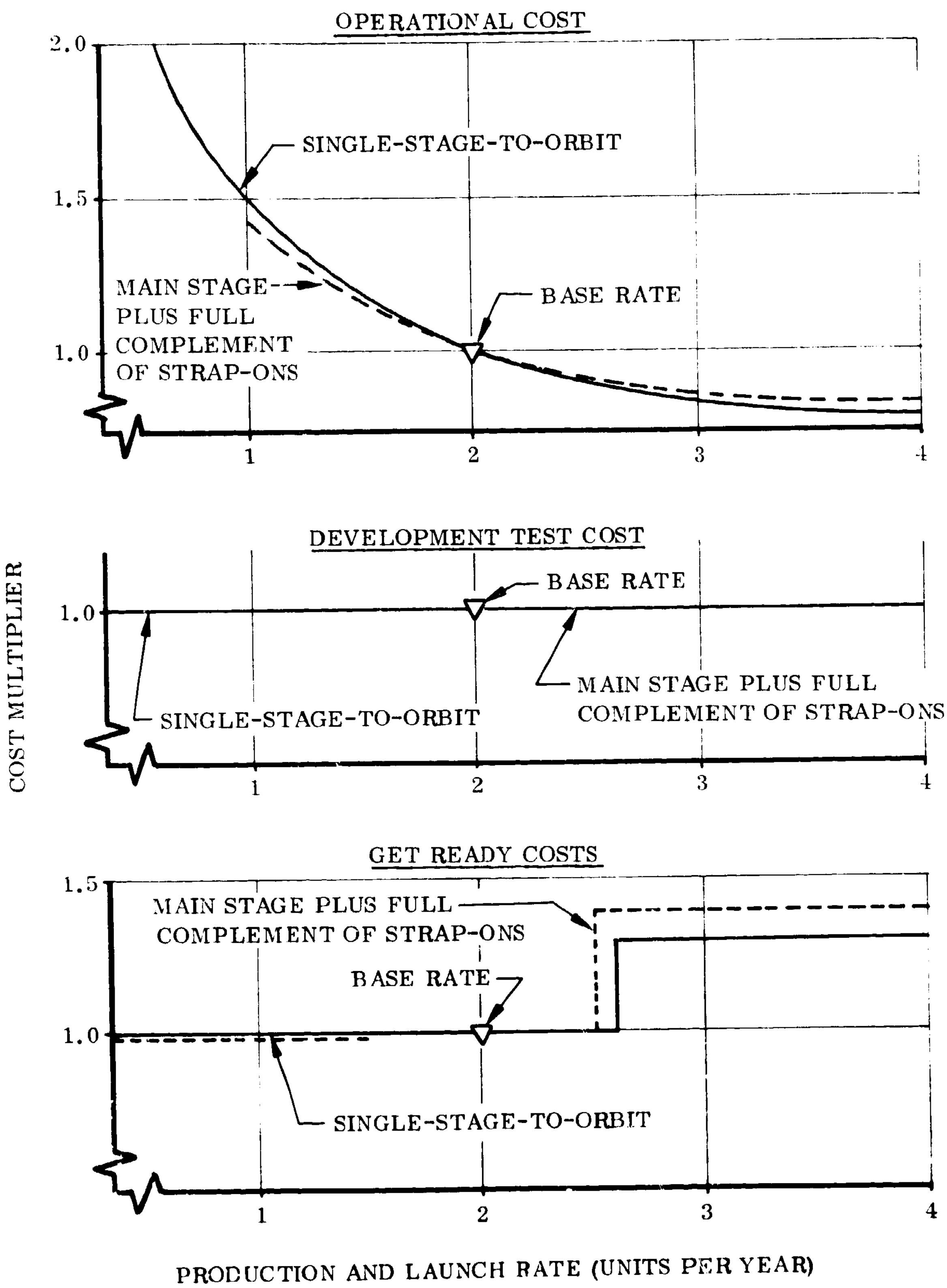


FIGURE 5.1.6.0-2 PRODUCTION AND LAUNCH RATE EFFECTS ON COSTS

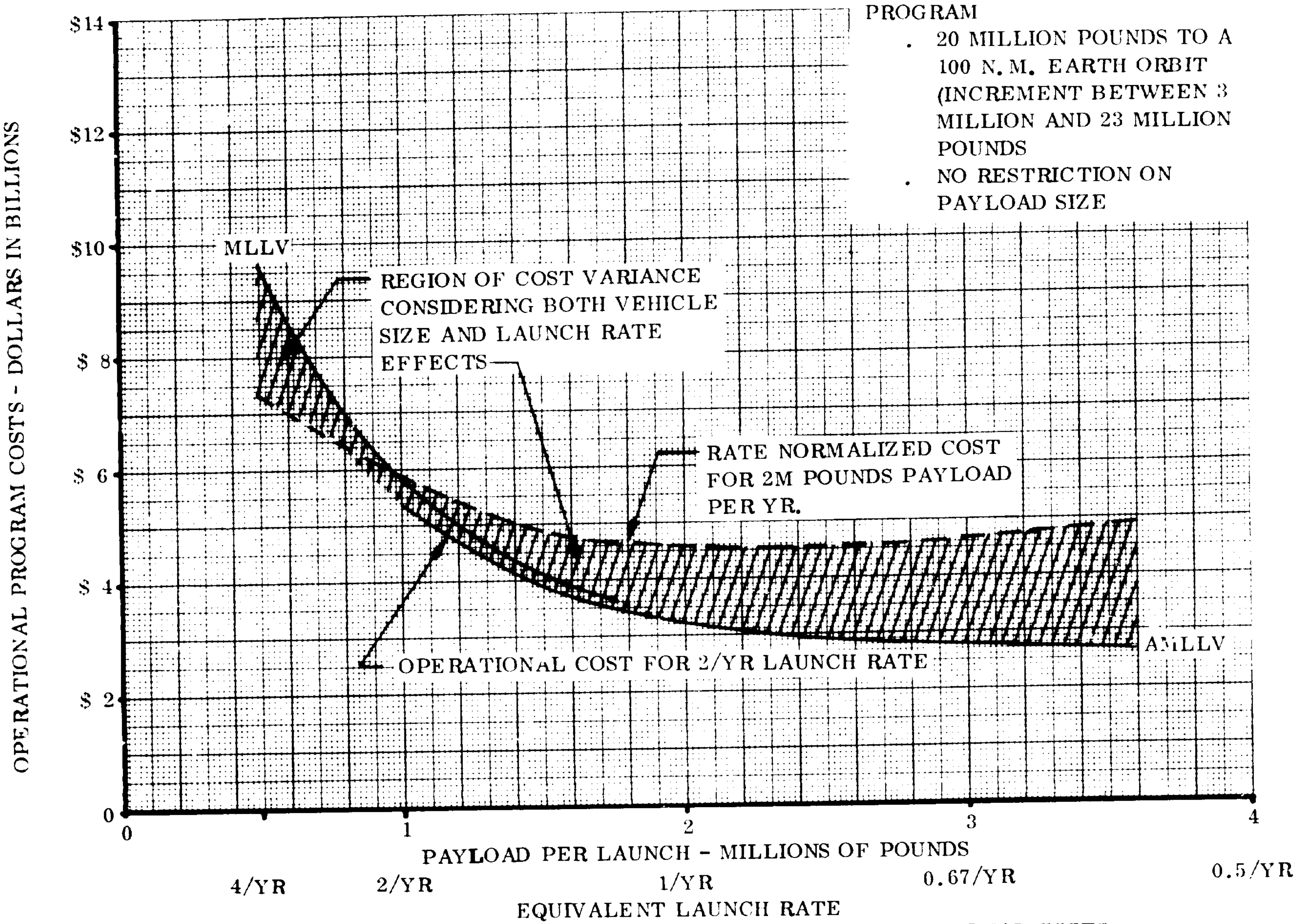


FIGURE 5.1.6.0-3 EFFECTS OF LAUNCH RATE BIAS ON OPERATIONAL COSTS

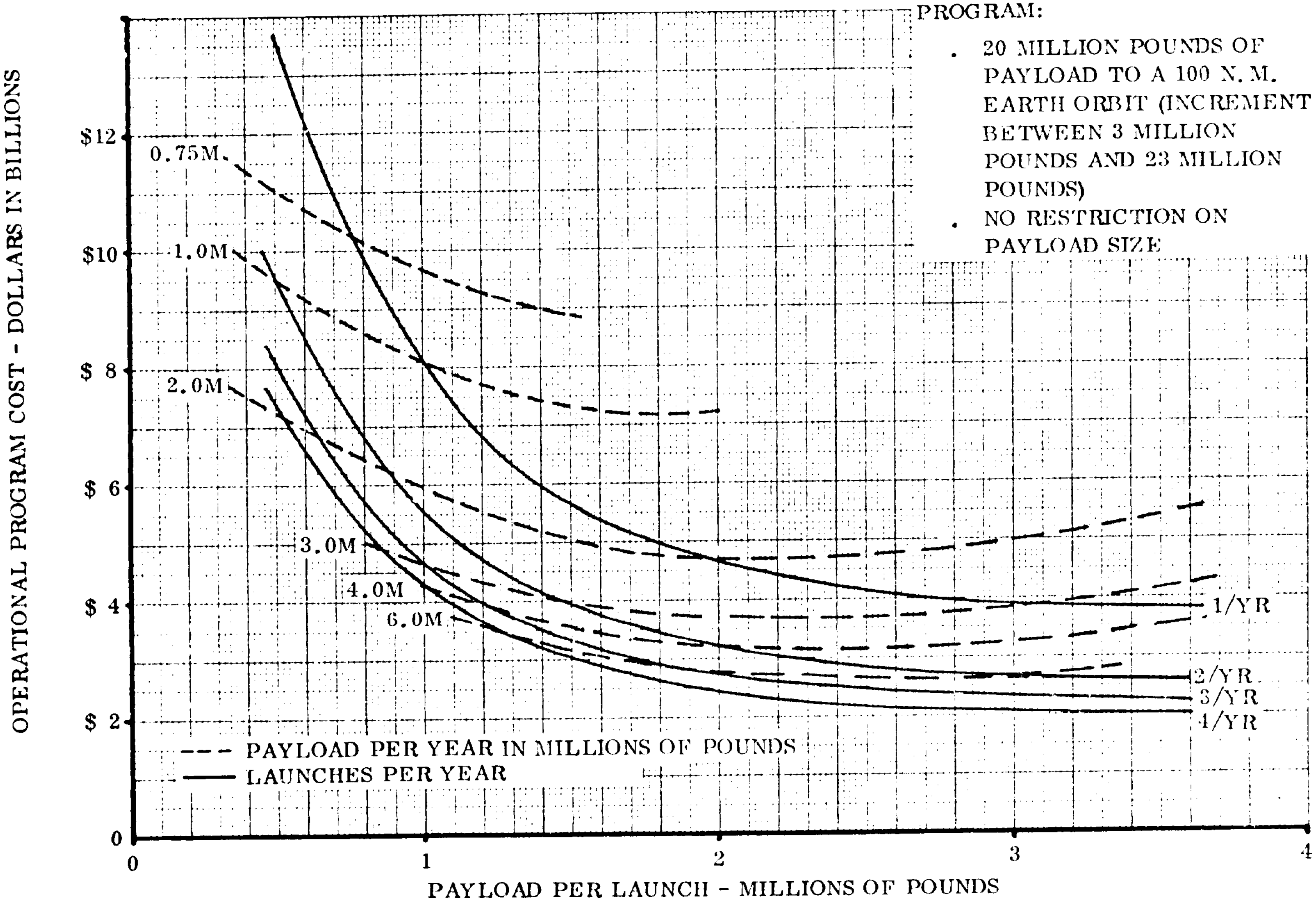


FIGURE 5.1.6.0-4 OPERATIONAL PROGRAM COSTS VERSUS ANNUAL PAYLOAD REQUIREMENTS (AS EFFECTED BY LAUNCH RATE)

.. .3 (Continued)

programs which require larger quantities of payload per year will have lower costs if they utilize vehicles with payload capabilities of slighly in excess of 2.0M pounds.

NOTE: The data shown on the aforementioned figures, while indicative of trends, should not be applied directly for quantitative comparisons. For lower launch rates, modifications of operational procedures and philosophy could reduce the rate impact on cost.

.2 PERFORMANCE/COST POTENTIAL OF ENGINE OPTIONS

In the previously completed AMLLV study (Contract NAS2-4079), two different propulsion systems were evaluated for application to the main stage, i.e.: 1) the high pressure multichamber/plug propulsion system and 2) the 2000 psia toroidal/aerospike propulsion system. The propulsion system alternatives investi ted for the MLLV main stage, in this study, were:

a. The high pressure multichamber/plug propulsion system with a single position nozzle.

b. A high pressure multichamber/plug propulsion system with a two position nozzle.

c. The 2000 psia chamber pressure toroidal/aerospike with 8 modules (each producing one million pounds of thrust).

d. A 1200 psia chamber pressure toroidal/aerospike with 28 modules (each producing 286,000 pounds of thrust).

e. A 1200 psia toroidal/aerospike with 8 modules (each producing one million pounds of thrust).

The performance analyses of these various propulsion system options are presented in Volume II. In general, the multichamber/plug propulsion systems will provide the highest engine performance while the toroidal/aerospike propulsion systems will have the lowest weight. As a result of vehicle payload performance analyses, it was determined that the 2000 psia (high pressure) toroidal/aerospike engine will provide the best compromise between engine performance and engine weight. The use of either high pressure multichamber/plug or the 1200 psia (low pressure) toroidal/aerospike propulsion systems will result in lower vehicle payload capability.

This section reviews the performance data relative to the costs of the various engine systems to assess the performance/cost potential of the engine options. Section .2.1 assesses the relationship to program cost of the module size of the AMLLV

5.2 (Continued)

2000 psi toroidal/aerospike engine. Section 5.2.2 assesses relationship to program cost of the module size and chamber pressure of the MLLV toroidal/aerospike. Section 5.2.3 analyzes the relationship to program cost of the AMLLV multichamber/plug module size.

The multichamber/plug propulsion system costs were provided to The Boeing Company by the Pratt and Whitney Division of United Aircraft Corporation. The toroidal/aerospike propulsion system costs were supplied by the Rocketdyne Division of North American Rockwell Corporation.

5.2.1 Effects of AMLLV Toroidal/Aerospike Engine Module Size on Program Cost

The get ready, development test, and first unit costs for the toroidal/aerospike propulsion system were provided for two different 2000 psia toroidal/aerospike propulsion systems: 1) an eight module system with a total thrust of 16 million pounds (two million pounds thrust per module), and 2) a sixteen module system with a total thrust of 16,000,000 pounds (one million pounds thrust per module).

Figure 5.2.1.0-1 illustrates program costs relative to quantity of operational payload delivered to a 100 nautical mile orbit by various AMLLV configurations employing the two different engine module sizes. The costs for the single-stage-to-orbit vehicle indicate that use of the smaller module (one million pound thrust module) will result in slightly lower program costs for small quantities of operational payload than will the use of the propulsion system with the two million pound thrust module. As the amount of payload to be delivered to orbit is increased beyond approximately twelve million pounds use of the larger module will, however, become more economical.

Two other vehicle configurations are also shown: 1) an AMLLV vehicle consisting of a main stage plus six SRM strap-on stages and 2) an AMLLV vehicle consisting of a main stage plus 12 SRM stages. Each of these configurations were also costed with the eight two million pound thrust module and the sixteen one million pound thrust toroidal/aerospike propulsion system. In both instances, the costs for the vehicles with the two million pound modules will be initially slightly higher than those of the vehicles with the one million pound modules. The two million pound module vehicles will become more cost effective as the required total payload increases beyond 27 and 42 million pounds for the main stages plus six SRM vehicles and the main stage plus twelve SRM vehicles, respectively.

Use of either the larger or smaller modules will not significantly effect the overall program cost. The costs of the two million pound module toroidal/aerospike propulsion system for any configuration will be 68 million dollars

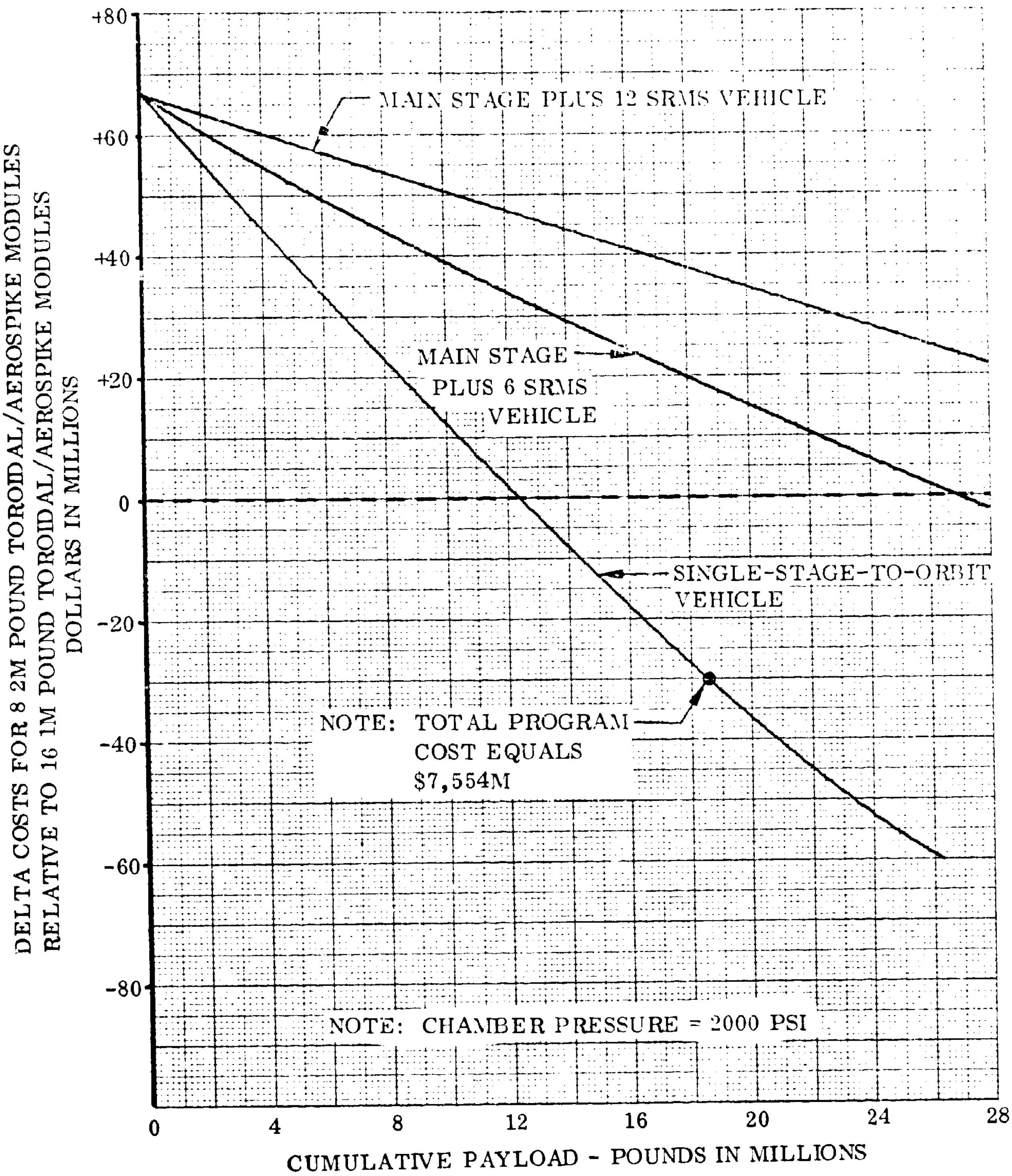


FIGURE 5.2.1.0-1 RELATIVE PROGRAM COSTS FOR AMLLV CONFIGURATIONS WITH TOROIDAL/AEROSPIKE PROPULSION SYSTEM OPTIONS ON THE MAIN STAGE

5.2.1. (Continued)

greater than that of the one million pound module thrust toroidal/aerospike propulsion system during the get ready and the development test phases. This difference will be amortized by the lower production cost of the two million pound thrust modules such that the larger modules become more cost effective for the larger programs. The program cost savings attributable to use of the larger modules will be approximately 30 million dollars for a program consisting of 18 launches of the AMLLV single-stage-to-orbit vehicle. This saving will represent a total program cost saving, however, of only 0.4 percent as the overall program cost for development and launch of 18 operational vehicles will be 7,554 million dollars.

5.2.2 Effect of MLLV Toroidal/Aerospike Engine Module Size and Chamber Pressure on Program Costs

The three different toroidal/aerospike engine systems investigated for the main stage of the half size MLLV vehicle were:

a. A 2000 psia chamber pressure system with eight modules, each producing one million pounds of thrust.

b. A 1200 psia chamber pressure system with eight modules, each producing one million pounds of thrust.

c. A 1200 psia chamber pressure system with 28 modules, each producing 286,000 pounds of thrust.

Figure 5.2.2.0-1 shows relative total program cost as a function of the cumulative amount of payload delivered to 100 NM earth orbit for three different MLLV configurations for the three engine systems. The configurations shown are (1) a single-stage-to-orbit vehicle, (2) a vehicle consisting of a main stage plus four strap-on stages and (3) a vehicle consisting of a main stage plus eight strap-on stages.

For all of the three vehicle configurations, the differences in costs attributable to the various engine systems employed on the main stage will be only a minor portion of the overall program costs. With the single-stage-to-orbit vehicle, the 1200 psia engine systems will be the more cost effective for programs with total payload requirements of less than two to three million pounds. Beyond this point, the 2000 psi toroidal/aerospike propulsion system will be more cost effective. While the 1200 psia propulsion system can use existing J-2 turbo pump technology, the higher performance that can be obtained with the 2000 psi propulsion system will soon offset the higher costs required for development of the new turbo machinery. Similar trends, which favor the 2000 psi engine system, are shown for the configurations employing strap-on SRM stages.

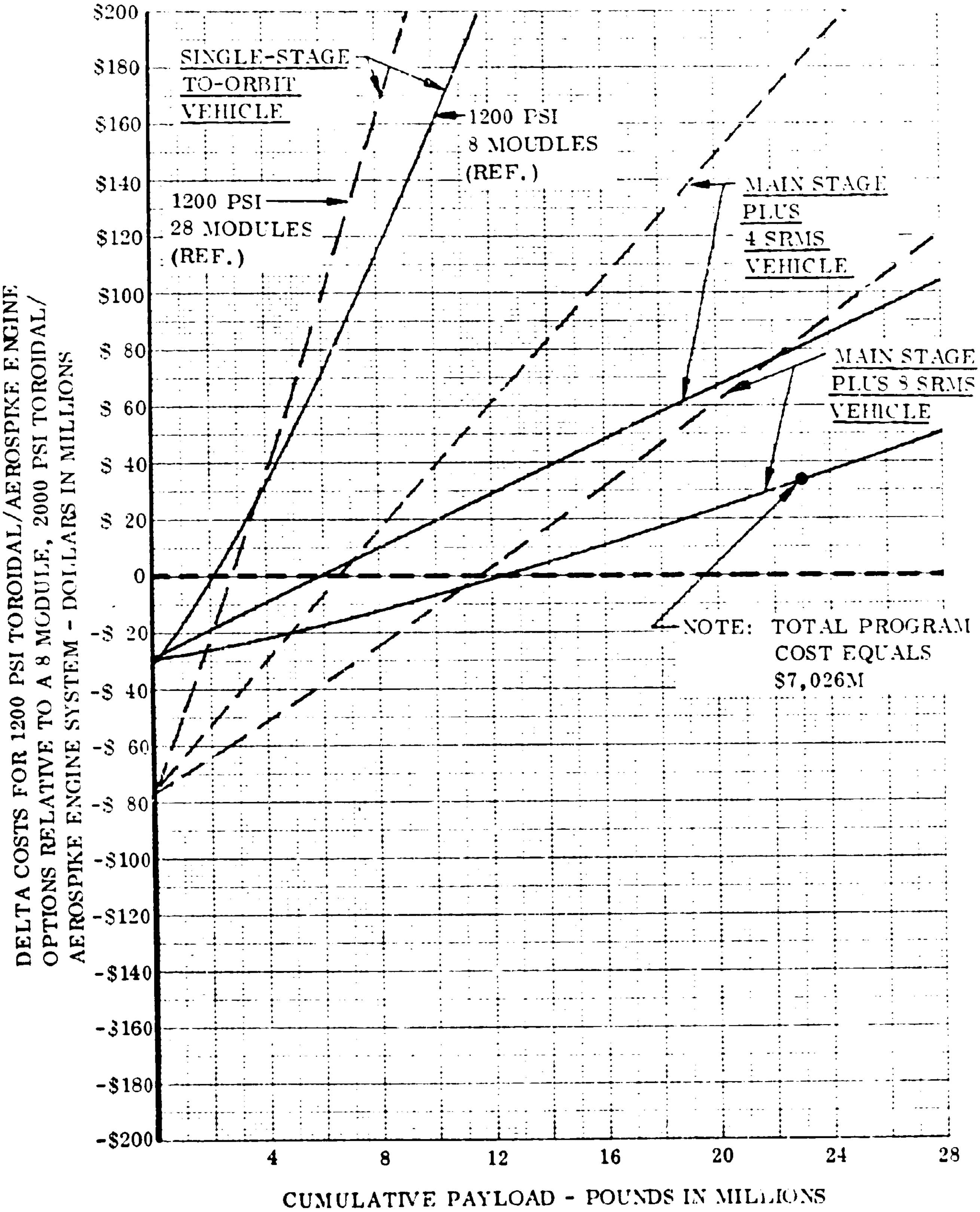


FIGURE 5.2.2.0-1 RELATIVE PROGRAM COSTS FOR MLLV CONFIGURATIONS WITH TOROIDAL/ AEROSPIKE PROPULSION SYSTEM OPTIONS ON MAIN STAGE

5.2.2 (Continued)

Compared to the 28 module 1200 psia system, the reduced production cost attributable to the larger module size will give the 8 module 1200 psia engine system a cost advantage.

The single-stage-to-orbit configurations will be more cost sensitive to the engine options than will be configurations employing strap-on stages. Overall program costs, in any case, however, will not be significantly effected. For example, a program cost differential of $200 million dollars between engine options for the single-stage-to-orbit vehicle will represent a change in total program costs of approximately 2.4 percent.

5.2.3 Effects of Multichamber/Plug Module Size on Costs

During the AMLLV study program, the multichamber/plug module size effects on engine performance and weight were investigated. Some degradation in the amount of payload delivered to orbit by the single-stage-to-orbit vehicle was shown to occur as the engine module size was increased (with total stage thrust held constant). This decrease was due 1) to the increased stage structural weight required to react the more concentrated engine thrust loads and 2) the sea level effects of the required overexpanded nozzle.

It would, therefore, be advantageous from the performance standpoint to have as many modules as possible. Cost trades were conducted, considering the AMLLV single-stage-to-orbit, the number of modules to optimize cost/performance. Figure 5.2.3.0-1 shows that the overall program costs for engine systems incorporating the larger modules generally will be slightly less than those of engine systems with the smaller modules. While the non-recurring costs of engines with smaller modules will be considerably less than those of engines with larger modules, the production costs will be less for the engines with the larger modules.

5.3 STRAP-ON STAGE CONFIGURATION PERFORMANCE COST TRADES

In the prior AMLLV study, the payload capability of the core vehicle was found to be significantly increased through the utilization of strap-on stages. The vehicle performance with both liquid propellant strap-on stages and solid rocket motor (SRM) strap-on stages was investigated. The strap-on stage diameter and amount of propellant carried in these stages as well as the number of stages were investigated.

For the MLLV half size vehicle configuration investigated in this current study activity, only SRM strap-on stages were investigated. Strap-on stage

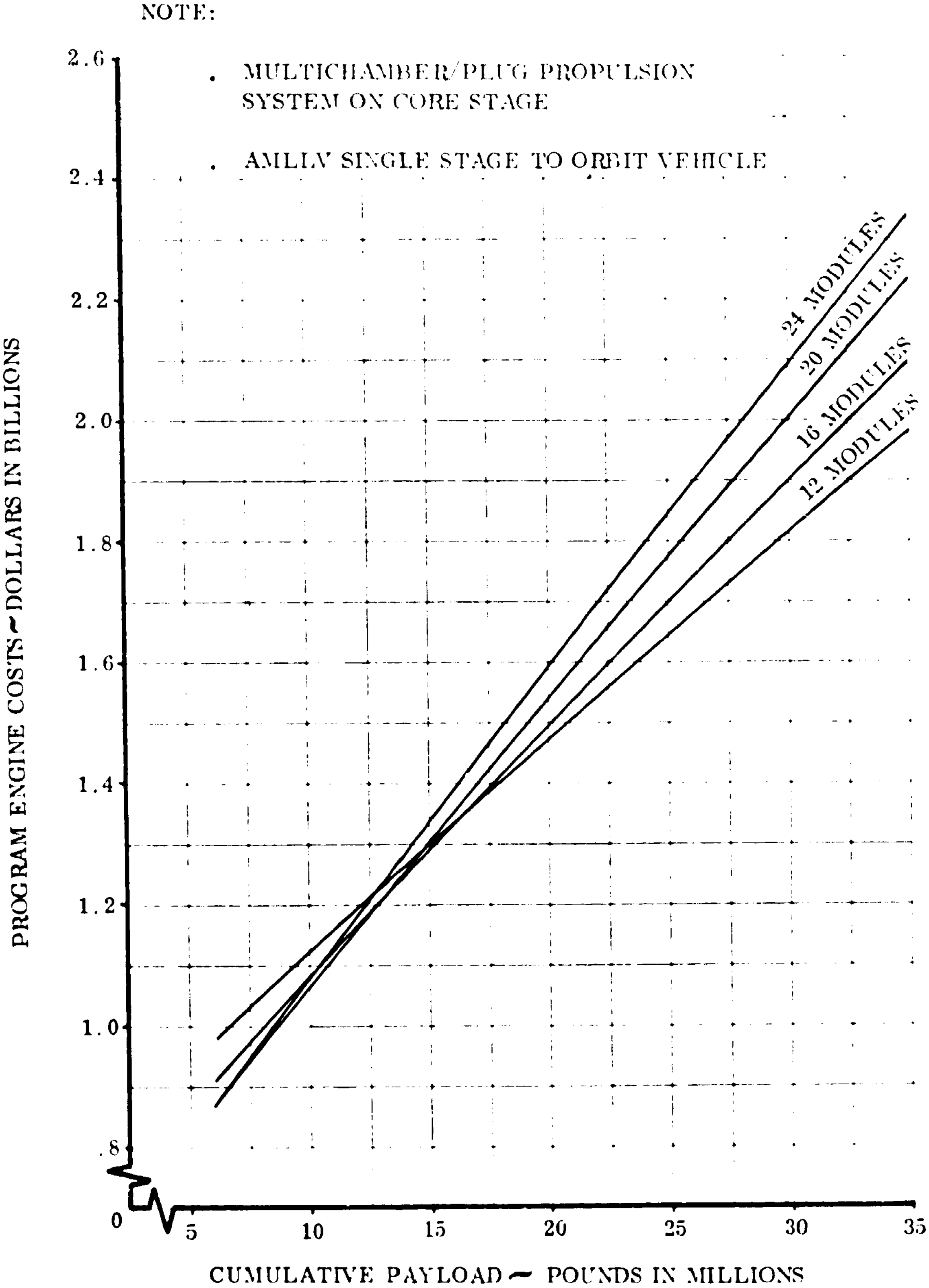


FIGURE 5.2.3.0-1 PROPULSION SYSTEM PROGRAM COSTS FOR VARIABLE NUMBER OF MODULES

5.3 (Continued)

diameters of 156 and 260 inches and the method of staging these SRM strap-on stages were examined. This performance trades activity is reported in Volume II.

This section reports the results of performance/cost trades relative to size, type and staging sequence of strap-on stage propulsion systems.

5.3.1 Liquid Propellant Strap-On Stages vs. Solid Rocket Motor (SRM) Stages

The liquid propellant strap-on stages are an alternative for the solid rocket motor (SRM) stages. For the purpose of this comparison, it was assumed that the costs for development, test and manufacture of the liquid stage would be the same as those for the SRM stage. The comparison of the liquid strap-on stage to the SRM stage was, therefore, based on relating comparable post-manufacturing tests, procedures and operations. The liquid propellant strap-on stages for this comparison were assumed to be 260 inches in diameter.

The SRM stage is described from development through manufacture and usage in Volume III, paragraph 4.2.9 - SRM Development Tests, paragraph 4.2.10 - Flight Tests, Section 5.4 - SRM Manufacturing Plan and Section 7.0 - Launch Plan.

Table 5.3.1.0-1 outlines the processing of the SRM stage and a comparable liquid stage from the manufacturing site to the launch facility and through launch. Costs for most of the operations will be similar for the two stages, and are not listed. Where substantial differences will exist, either in "get ready" non-recurring costs or operating and maintenance recurring costs, these costs are noted. The prime assumption is as stated above that the costs of the two stages, upon reaching the manufacturing facility dock site, will be equal. This includes the cost of the liquid fuel for the liquid stages. Major differences occurring in processing after this established baseline, are noted as delta costs.

Weights will be a factor in transporation and handling costs. The 260 inch SRM stage for the full size AMLLV will weigh approximately 4,200,000 pounds, while the dry weight of a comparable liquid stage will be approximately 172,000 pounds. Storage requirements at the launch site will also affect transportation and handling costs. The weight and safety requirements of the SRM stages dictate that they will remain on the barge, moored in a protected location until needed for launch.

Recurring processing costs for the two configurations will differ very little, and will be generally more or less compensating. An exception is the increased

TABLE 5.3.1.0-1 SRM STAGE VERSUS LIQUID PROPELLANT STRAP-ON STAGE POST-MANUFACTURING TO LAUNCH COST COMPARISONS

SOLID ROCKET MOTOR (SRM) STAGE PROCESSING ACTIVITIES	SRM STAGE COST	DELTA SRM (LPO STG.)	LIQUID STAGE COST	LIQUID PROPELLANT STAGE PROCESSING ACTIVITIES
1. Load on Barge at Manufacturing Facility	Fueled SRM Cost	Same	Strap-On Stage & Fuel Cost	1. Load on Barge at Manufacturing Facility
2. Transport to KSC SRM Stage Receiving Area	$ 221,000	$ 95,000	$ 126,000	2. Transport to KSC Launch Facility
3. Perform Receiving Inspection on Barge		Same		3. Unload Stage Onto Pad W/ Crane Hoist
4. Store on Barge Until Required on Liquid Stage				4. Transfer to Shop Area & Conduct Receiving Inspection
5. Unload SRM from Barge onto Pad W/ Roll Ramp Actuators				5. Store in Pad Storage Area
6. Move by Gantry Crane to Rotation Slip & Rotate				6. Move to Silo and Insert for Vehicle Stacking
7. Move to Silo and Insert				7. Align Stage and Attach to Main Stage
8. Align SRM Stage and Attach to Core Stage				8. Vehicle Integration, Test and Checkout
9. Vehicle Integration, Test and Checkout				9. CDDT - Fueling and Defueling Operations
10. CDDT				10. Prepare for Launch - Countdown Sequence
11. Prepare for Launch - Countdown Sequence				11. Launch
12. Launch		Same		
DELTA TOTAL FOR RECURRING COSTS		$ 95,000		
NON-RECURRING "GET READY" COSTS				NON-RECURRING "GET READY" COSTS
1. Barges - 13 Required	$26,000,000	$20,816,000	$ 5,184,000	1. Barges - 2 Required
		(3,696,000)	3,696,000	2. Transporters - 16 Required
		(246,000)	246,000	3. Tow Vehicles - 5 Required
2. Gantry Equipment and Unloading Crane For SRM Stages	29,155,000	17,155,000	12,000,000	4. Gantry Crane W/O SRM Loads
3. Propellant Storage & Distribution	83,250,000	(17,000,000)	100,250,000	5. Propellant Storage, etc. Increased for Liquid Stages
DELTA TOTAL FOR NON-RECURRING COSTS		$1[illegible],029,000		

5.3.1 (Continued)

SRM transportation costs which are attributable to the requirement to store the SRM stages on the barges until all the stages have been received, and the vehicle is scheduled for launch. This will necessitate one barge for each SRM stage, plus one spare. (Only two liquid strap-on stage barges will be required, as liquid stages will be off loaded immediately upon arrival at the launch facility. The two barges can each make two round trips per month, if required.) The SRM barge operating and maintenance costs for each launch cycle of six months will exceed the liquid stage barge operating and maintenance costs by $95,000.

The initial non-recurring costs of the 13 SRM stage barges will be $20,816,000 more than the cost of the two liquid stage barges.

It will take more time and equipment to lift the heavier SRM stages. This difference will be partially compensated for by the fact that the SRM stage will undergo only one handling sequence after barge off-loading and will be placed directly in the silo for mating to the main stage. The liquid strap-on stages will first go to the receiving area on the pad, and then will be placed in a subterranean storage room on the pad until needed for stacking the vehicle. While the operating costs of handling the SRM's and the liquid stage on the launch pad will, therefore, be approximately the same, there will be a $10,610,000 additional cost for the larger gantry required to lift and transport the SRM stages.

Propellant storage and distribution capacities must be increased at the launch facility, if liquid propellant stages are to be used. The cost of additional fuel storage barges, pumping and distribution facilities is estimated at $17,000,000.

As shown (considering the prime assumption), these differences will result in an approximate $17M (1.3%) savings in the AMLLV non-recurring get ready costs attributable to use of the liquid strap-on stages. Similarly, the recurring costs for the AMLLV maximum payload vehicle would be reduced by $95K (0.02%).

5.3.2 Dollars Available for Strap-On Stage Options

The strap-on stage options investigated during the AMLLV and MLLV vehicle conceptual design studies were the 260 inch and the 156 inch solid propellant rocket motor stages, and the 260 inch liquid propellant strap-on stages.

Costs for the entire SRM stage program were developed for both the AMLLV and MLLV. These costs include the costs of design, development and test, facilities, manufacture, transportation, and launch costs.

A summary of all costs associated with the 260" SRM stage, from drawing board to launch pad, appear in Figures 5.3.2.0-1 and 5.3.2.0-2 as dollars available for AMLLV or MLLV strap-on stage options. These figures contain individual data for specific program sizes considering the maximum payload vehicles.

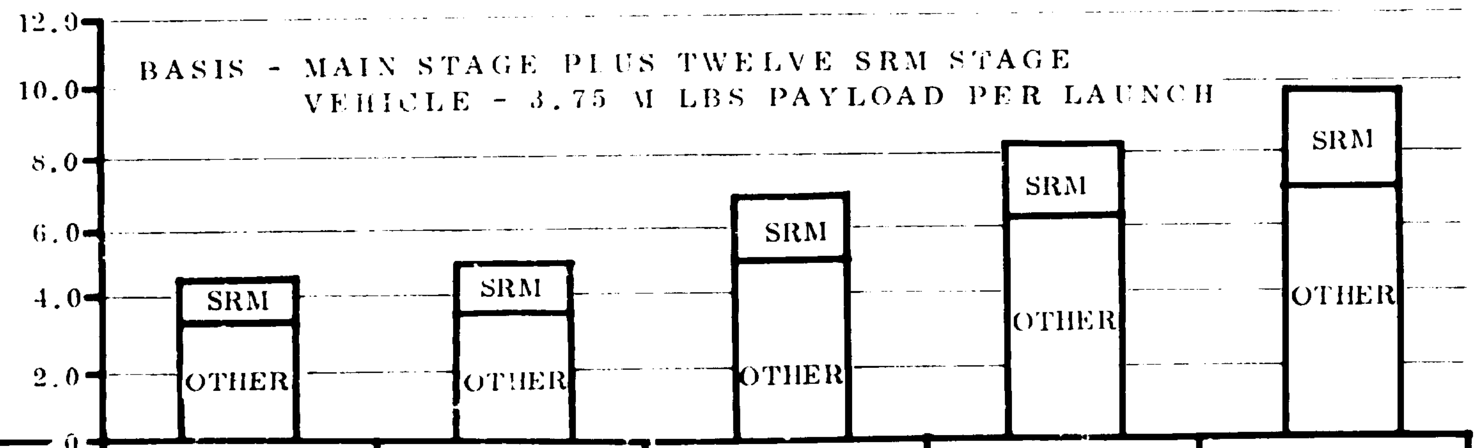
* C_S COST OF SOLID ROCKET MOTOR STRAP-ON STAGES (RECURRING)

** C_F = COST OF FACILITIES (MANUFACTURING, TRANSPORTATION, TEST AND LAUNCH) CHARGEABLE TO SRM's. (RECURRING)

*** DOLLARS AVAILABLE FOR STRAP-ON STAGES, SOLID OR LIQUID FUELED

PROGRAM COSTS

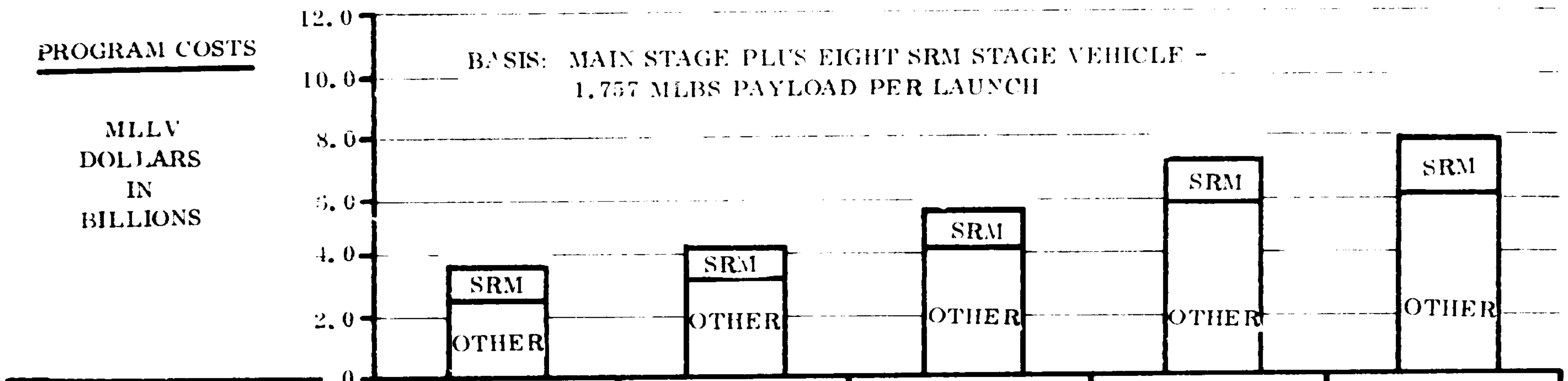
AMLLV DOLLARS IN BILLIONS



AMLLV FLIGHTS	2 R&D	4 FLIGHTS (2 OPERATIONAL)	8 FLIGHTS (6 OPERATIONAL)	12 FLIGHTS (10 OPERATIONAL)	16 FLIGHTS (14 OPERATIONAL)
PAYLOAD IN MILLIONS OF POUNDS →	DUMMY	7.5 M. LBS.	22.5 M. LBS.	37.5 M. LBS.	52.5 M. LBS.
			DOLLARS IN THOUSANDS		
SRM Non-Recurring Costs	$ 614,486	$ 614,486	$ 614,486	$ 614,486	$ 614,486
*C_S	273,900	505,400	962,285	1,401,917	1,830,662
**C_F	54,800	70,[illegible]00	102,200	133,800	165,400
***SRM Totals	943,186	1,190,486	1,678,971	2,150,203	2,610,548
Vehicle Totals (Less SRM's)	3,372,437	3,960,137	5,103,537	6,196,137	7,279,137
GRAND TOTAL	$4,315,623	$5,150,623	$6,782,598	$ 8,346,340	$ 9,889,685

FIGURE 5.3.2.0-1 DOLLARS AVAILABLE FOR AMLLV STRAP-ON STAGES

* C_S - COST OF SOLID ROCKET MOTOR FOR STRAP-ON STAGES (RECURRING)
** C_F - COST OF FACILITIES (MANUFACTURING, TRANSPORTATION, TEST AND LAUNCH) CHARGEABLE TO SRM's. (RECURRING - O&M)
*** - DOLLARS AVAILABLE FOR STRAP-ON STAGES, SOLID OR LIQUID FUELED



MLLV FLIGHTS	2 R&D	4 FLIGHTS (2 OPERATIONAL)	8 FLIGHTS (6 OPERATIONAL)	12 FLIGHTS (10 OPERATIONAL)	16 FLIGHTS (14 OPERATIONAL)
PAYLOAD IN MILLIONS OF LBS.	DUMMY	3.70 M. LBS.	11.10 M. LBS.	18.50 M. LBS.	26.90 M. LBS.
MLLV UNITS			DOLLARS IN THOUSANDS		
SRM Non-Recurring Costs	$ 507,446	$ 507,446	$ 507,446	$ 507,446	$ 507,446
*SRM C_S Costs	155,660	285,500	544,100	793,000	1,035,700
**SRM C_F Costs	41,200	54,200	80,200	106,200	132,200
***SRM Totals	704,306	847,146	1,131,746	1,406,646	1,675,346
Vehicle Totals (Less SRMs)	2,775,944	3,283,818	4,256,318	5,826,918	6,131,718
GRAND TOTAL	$3,480,250	$4,130,964	$5,388,064	$7,233,564	$ 7,807,064

FIGURE 5.3.2.6-2 DOLLARS AVAILABLE FOR MLLV STRAP-ON STAGES

5.3.2 (Continued)

Each MLLV or AMLLV vehicle as costed has a main stage and a full compliment of SRM strap-ons; e.g., 8 for the MLLV and 12 for the AMLLV.

The tables appearing on each figure show the total program costs (less SRM's), the SRM strap-on stage non-recurring costs and the SRM strap-on stage recurring (C_S and C_F) costs. The totals of the SRM stage costs appears on the table and on each bar on the bar charts. These SRM totals (as designated by a triple asterisk) represents amounts available within each program for implementation and operation of any alternative strap-on stage.

5.3.3 Cost Comparison of MLLV Vehicle Configuration with Strap-On 156 Inch or 260 Inch SRM Strap-On Options

During the MLLV half size vehicle conceptual design study activity as reported in Volume II of this final report, it was concluded that the 156 inch strap-on stage with one half the thrust level and one half the propellant weight of the 260 inch SRM stage would be an acceptable option for the MLLV strap-on family. Twice the number of strap-on stages would be required for the maximum vehicle configuration with the 156 inch SRM's as required for that with the 260 inch SRM stages.

In Volume III, Resources Implications, a comparison was made of the method of transportation of the 156 inch motor segments to the launch site versus delivery of the completed 156 inch stage. The various launch operational procedures and sequence options for the 156 inch stage were also analyzed. The transportation and facility requirements were identified. This data, coupled with cost data obtained for 156 inch strap-on motors by Boeing and other contractors on previous studies provided the input data for the cost comparison.

Table 5.3.3.0-I shows comparable costs for get ready and development test costs associated with the 260 inch and 156 inch MLLV SRM strap-on stages.

The fixed get ready costs for the 156 inch SRM stage will be approximately $45,000,000 less than those shown for the 260 inch SRM stage. The principal cost differences will be due to:

a. Slightly reduced launch complex facility costs. These will be the result of lower cost handling and lifting devices required for the 156" SRM segments. (These segments weigh less than one half million pounds per segment versus the approximate three and one half million pounds of the monolithic 260 inch SRM stages.)

b. Reduced SRM facility and tooling costs. Approximately $19,000,000 less will be required for the 156 inch SRM stage. As the 260 inch SRM stage will be delivered as a complete stage versus the 156 inch motor being

TABLE 5.3.3.0-I GET READY AND DEVELOPMENT TEST COSTS FOR MLLV CONFIGURATION WITH EIGHT 260" SRM STRAP-ON STAGES VERSUS SIXTEEN 156" SRM STRAP-ON STAGES (DOLLARS IN THOUSANDS)

FUNCTION OR COMPONENT	156" SRM STAGE	260" SRM STAGE
Fixed Get Ready Costs		
GSE	$ 3,100	$ 3,072
Michoud Facility	7,420	8,434
Launch Complex Facility	151,000	162,470
SRM Facility and Tooling Plus Design	25,000	44,131
Stage Structure Design and Tooling	19,500	32,745
Forward Skirt	19,729	19,729
Subtotal	225,749	270,581
Quantity Sensitive - Get Ready Costs		
GSE	14,000	15,690
Facility, Manufacturing and Launch	32,000	42,170
Subtotal	46,000	57,860
Development Test Costs		
Stage Structural Test	2,287	3,789
Manufacturing Development	118	118
PFRT SRM	42,900	69,321
Other	9,500	14,758
Stage Structure	21,000	33,037
Wind Tunnel and SDF	4,975	4,975
Facility Test	15,820	30,219
DTV	18,508	18,508
R&D Flights (2)	224,443	196,207
Static Load	2,880	4,840
Subtotal	342,431	375,772
TOTAL	$614,180	$704,213

- 156" SRM Stage Contains 1.45 Million Pounds of Propellant
- 260" SRM Stage Contains 2.90 Million Pounds of Propellant

5.3.3 (Continued)

delivered in segments, considerably less tooling will be required for assembly and checkout at the SRM facility.

c. Smaller diameters and lower weight for the associated stage structure design and tooling. Approximately thirteen million dollars lower cost will result with smaller 156 inch SRM stage structures.

Other get ready costs are those items of ground support equipment and facility manufacturing and launch equipment which are sensitive to the quantity of solid motor segments and/or motors to be fabricated and to the number of SRM stages to be launched. The GSE costs for the 156 inch SRM will be approximately the same as the 260 inch SRM. Although there will be a considerable difference in the weight of the items to be handled by the ground support equipment, the larger quantities and number of subassemblies (segments) that will be required for the 156 inch SRM will make their costs comparable to the 260 inch SRM GSE costs. There will be a decrease of approximately $12,000,000 between the 156 inch stage and the 260 inch stage costs for the quantity sensitive elements of the facilities for manufacturing and launch. The 156 inch motors can be manufactured in a simpler manufacturing facility than those required for the 260 inch motors. The 260 inch motors will require cast, cure and test facilities which cost between two to three million dollars apiece. At least four would be required to meet the launch rate required by the program. For the 156 inch motors, the segments will be cast in smaller increments and require less complex facilities.

A difference of approximately $33,000,000 will exist between the 156 inch SRM stage and the 260 inch SRM stage development test costs. The major differences will be in the PFRT costs where approximately $45,000,000 more will be required for the 260 inch SRM stage tests. The same number of SRM's will be involved in the test program, however, the propellant in the 156 inch motors will be half that required for the 260 inch motors. In addition, all other structures will be reduced in size and weight and, therefore, cost considerably less. A cost difference of approximately $15,000,000 will exist in the facility test vehicle costs. The structural elements, transportation costs, and launch operation costs for the 156 inch motors will make up the major portion of this difference. These costs will be considerably less for the 156 inch SRM stage as it goes through the facility, handling and checkout procedures than those for the 260 inch SRM stage. All of the other costs shown in the development test program will be approximately the same for the two configurations (except for the R&D flights).

Vehicle programs with increasing payload requirements were costed to determine the break even point between the two configurations. Three different size vehicle programs were examined. These programs consisted of four vehicles which placed 7,000,000 pounds of payload into 100 NM orbit, nine vehicles which put up 15,800,000 million pounds of payload, and 20 vehicles which put up 35,100,000 million pounds of payload. With only four vehicles, the 156 inch SRM program cost will be 11% less than the program cost for 260 inch strap-ons. The cost difference is the result of the greater "get ready" and development test costs for the 260 inch SRM stages as compared to the 156 inch SRM stage. At approximately nine vehicles or 15,800,000 pounds of payload, the lower get ready and development test costs for the 156 inch SRM will be offset by the lower production costs for the 260 inch SRM stages. At this point, the overall cost of the 260 inch SRM program will be slightly lower than that of the 156 inch SRM. When the program is increased to 20 vehicles, there will be a considerable savings with the vehicle configuration having 260 inch SRM strap-ons. These comparative results are shown in Figure 5.3.3.0-1.

5.3.4 Cost Comparison of MLLV Configuration with Eight Strap-On 260 Inch SRM's - Sequentially Staged SRM's Versus Non-Sequentially Staged SRM's

The MLLV configuration consisting of a main stage plus eight strap-on 260 inch SRM's, operating in a zero stage mode, will have a payload capability to 100 NM of 1,757,000 pounds. In Volume II, the performance advantage of sequentially staging the 260 inch SRM stages was presented. For the sequential staging mode, six of the eight SRM stages would be ignited at liftoff, burned and separated after propellant depletion. The remaining two SRM stages would be then ignited. After their propellant depletion, they would be separated and then the main stage ignited. The payload with the sequentially staged SRM's would be approximately 1,950,000 pounds. (This payload value is a conservative approximation. The effects of drag losses and vehicle structural penalties induced by the SRM stages that are not ignited at launch must be considered in more detail analyses to better define the vehicle performance for this mode.)

The effects of sequentially staging the SRM's on the get ready costs, development tests costs and first unit costs were determined. It was determined that the following vehicle elements will be affected:

a. Instrument Unit - The instrument unit must be modified to provide the modified ignition and separation sequence of the SRM stages.

b. Main Stage - The main stage exclusive of the forward skirt must be structurally modified to withstand the greater payload weight and length. The base plug will require a significant increase in the ablative insulation since it now must withstand the solid motor exhaust gases for 260 seconds rather than for 130 seconds as with the non-staged configuration. The forward skirt structure will be significantly affected. During operation of the six SRM stages, six of the points at which the SRM stages are attached to the core vehicle will react the positive loads induced by the thrust of the

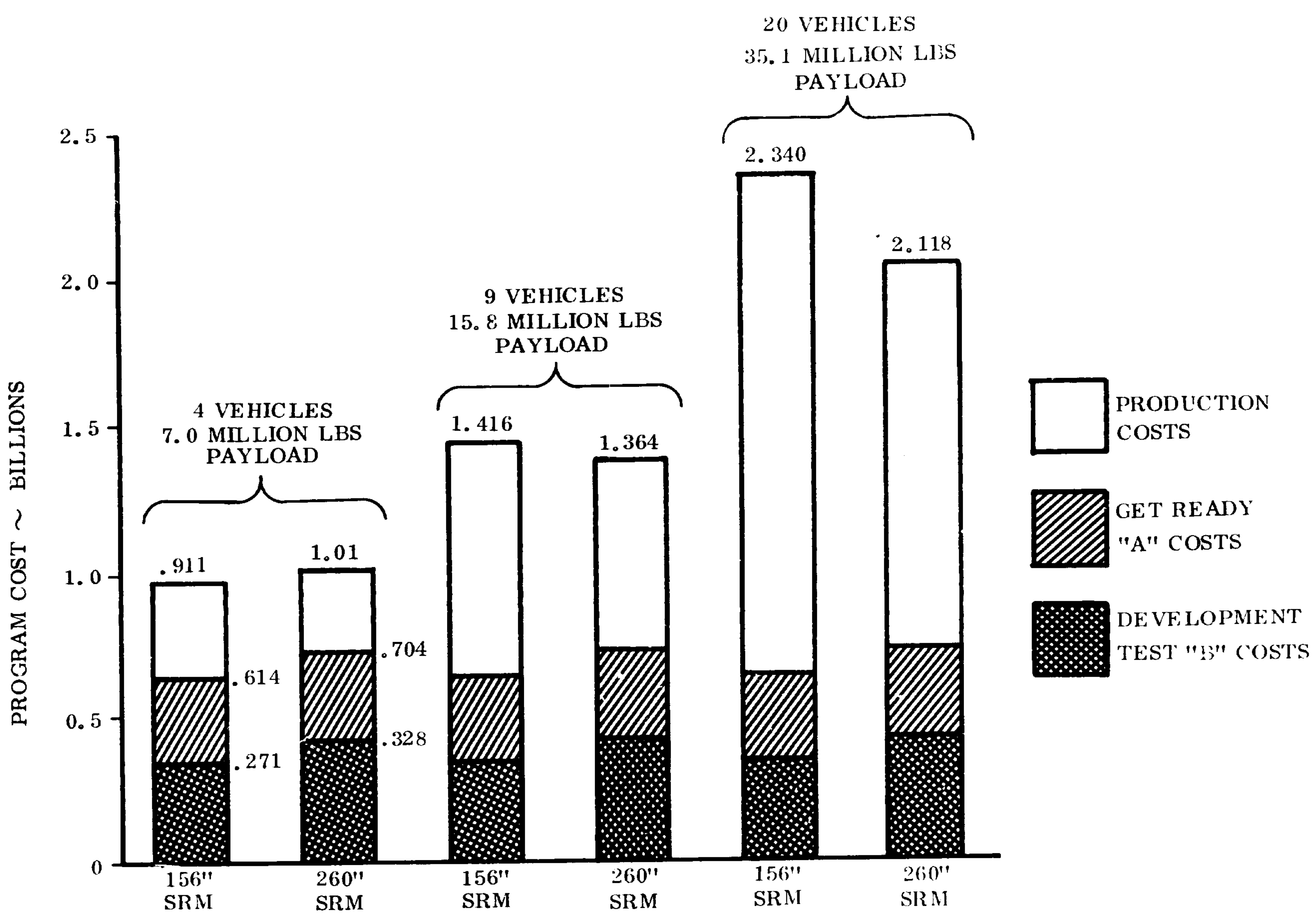


FIGURE 5.3.3.0-1 COST COMPARISON - MLLV CONFIGURATION WITH EIGHT 260" SRMS VERSUS MLLV WITH SIXTEEN 156" SRMS

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5.3.4 (Continued)

SRM stages while the remaining two SRM stage attachment points will react the negative loads due to the non-operation of these stages and to the drag induced by their weight. This will create unusual loads paths within the forward skirt and will necessitate some increase in its weight.

In addition to the vehicle changes, there are several areas which should be investigated during the get ready and development test phases. These include:

a. Wind tunnel analyses of the local aerodynamics and separation dynamics during staging. As the SRM stages will not be separated simultaneously, the spacings between the two remaining and the six being expended will be more critical than when all eight SRM stages are staged simultaneously.

b. Analyses of the separation motor requirements. With the tight clearance between the SRM stages being separated and those remaining, it may be necessary to modify the separation motors.

c. Increased structures testing of the main stage and strap-on stage forward skirts to account for the uneven load distribution.

d. Modification to the dynamic test activities to simulate for the condition of six SRM stages being ignited at launch, followed by ignition of the remaining two SRM stages after the six SRM stages are expended and separated. This will cause a minor modification to the dynamic test vehicle, tooling, equipment, tests and operations.

Table 5.3.4.0-I lists the various elements of get ready and development test costs showing those elements which will be modified. In addition, the cost of the non-sequentially staged standard condiguration is shown for comparison. The increase in the get ready and development test costs will be $1,788,000 (0.25 percent).

The recurring (first flight test unit) costs effects are summarized in Table 5.3.4.0-II.

The first unit cost for the SRM stage will be increased by approximately $600,000. Cost increases of $160,000 for the core stage will include those for modification of the forward skirt, a slight modification to the thickness of the tank walls, an increase in the base plug insulation, and slight modifications to the breadboard and the launch operations.

To provide a comparison of the cost effectiveness, a vehicle program consisting of 20 vehicles (2 R&D flights, 18 operational flights) using the sequentially staged method versus the non-sequentially stage method was costed. The vehicle

TABLE 5.3.4.0-I GET READY AND DEVELOPMENT TEST COSTS FOR MLLV CONFIGURATION WITH EIGHT 260" SRM STRAP-ON STAGES STANDARD VERSUS SEQUENTIALLY STAGED (DOLLARS IN THOUSANDS)

FUNCTION OR COMPONENT	260" SRM STAGE (USING SEQUENTIALLY STAGED SRMS)	260" SRM'S (ZERO STAGED)
Fixed Get Ready Costs		
GSE	$ 3,072	$ 3,072
Michoud Facility	8,454	8,434
Launch Complex Facility	162,470	162,470
SRM Facility and Tooling Plus Design	44,131	44,131
Stage Structure Design and Tooling	32,335	32,285
Forward Skirt	19,729	19,729
Subtotal	$270,191	$270,121
Quantity Sensitive - Get Ready Costs (Excluding R&D Flight Tests)		
GSE	15,690	15,690
Facility Manufacturing and Launch	42,210	42,170
Subtotal	$ 57,900	$ 57,860
Development Test Costs		
Stage Structural Test	3,809	3,789
Manufacturing Development	118	118
PFRT SRM	69,321	69,321
Other	14,758	14,758
Stage Structure	33,037	33,037
Wind Tunnel and SDF	5,533	4,975
Facility Test	30,219	30,219
DTV	19,508	18,508
Static Load	4,940	4,830
Subtotal	$181,243	$179,565
TOTAL	$509,334	$507,546

TABLE 5.3.4.0-II FIRST FLIGHT TEST UNIT COST COMPARISON OF SEQUENTIALLY STAGED MODE VERSUS STANDARD STAGED MODE FOR THE MLLV CONFIGURATION CONSISTING OF A MAIN STAGE PLUS EIGHT STRAP-ON 260 INCH SRM'S

	SEQUENTIALLY STAGED MODE	ZERO STAGED MODE
8 SRM Stages	$103,165,000	$102,565,000
Main Stage	372,638,000	372,478,000
MLLV Configuration Consisting of a Main Stage Plus Eight Strap-On Stages (Total Vehicle)	$475,803,000	$475,043,000

5.3.4 (Continued)

configuration used for this comparison consisted of a main stage plus eight 260 inch SRM stages. This analysis showed that the total cost of the program will be 8,987,900,000 for the vehicle configurations using ignition of all eight SRM stages at launch. This gave a cost effectiveness of $284 per pound of payload placed into orbit. Using the staged SRM sequentially staged concept, the total program cost will increase by approximately 15 million dollars to $9,002,900,000. In terms of cost effectiveness, the staged vehicle concept will, however, deliver payload to orbit at a cost of $256 per pound.

In summary, the staged vehicle concept will significantly increase the payload capability at only a minor increase in cost. This will result in a much more cost effective vehicle.

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6.0 COST EFFECTIVENESS EVALUATION OF ALTERNATIVE TECHNOLOGY APPLICATIONS

This section presents parametric cost and performance data and illustrates the methodology for its application to evaluate the cost effectiveness of alternative technology applications to the baseline MLLV and AMLLV families. Such evaluations can be used to determine the maximum dollars which can be expanded. for an advanced technology alternative to replace the technology specified for the baseline vehicle, without increasing overall cost for a specified program.

Application of technology alternatives to the main stage of either the MLLV or AMLLV families should result in a change of the overall vehicle weight for a given payload requirement. This change in vehicle weight will be reflected in the weight or size (and associated costs) of the major elements comprising the vehicle and of the required supporting facilities, equipment and tooling. Application of the relationships of technology, size and cost with the proper methodology will give the cost/performance potential of alternative technologies.

The following tools for evaluation of the cost/performance potential of alternative technology applications to the baseline MLLV and AMLLV families are provided and discussed in the subsequent sub-sections:

a. Relationship of required main stage size, for a given payload, as a function of specific impulse (I_{sp}) and mass fraction (λ').

b. Relationship of costs to main stage size.

c. Methodology for cost effectiveness evaluation with representative examples and conclusions.

6.1 RELATIONSHIPS OF REQUIRED MAIN STAGE SIZE TO TECHNOLOGY IMPROVEMENTS

Application of technology improvements, such as increasing the mass fraction or increasing the specific impulse will result in reduction of the required overall vehicle launch weight to place a given payload in orbit. Figure 6.1.0.0-1 through Figure 6.1.0.0-8 illustrate the relationships of mass fraction (λ'), and specific impulse (I_{sp}) as a function of the vehicle weight for a specified payload capability.

Figure 6.1.0.0-1 shows the required main stage weight of the AMLLV single-stage-to-orbit vehicle as a function of the main stage mass fraction (λ') for various values of specific impulse (I_{sp}). The baseline AMLLV main stage (with multichamber/plug propulsion system) is identified by the triangle which corresponds to the baseline stage weight of 11.8 million pounds, the associated

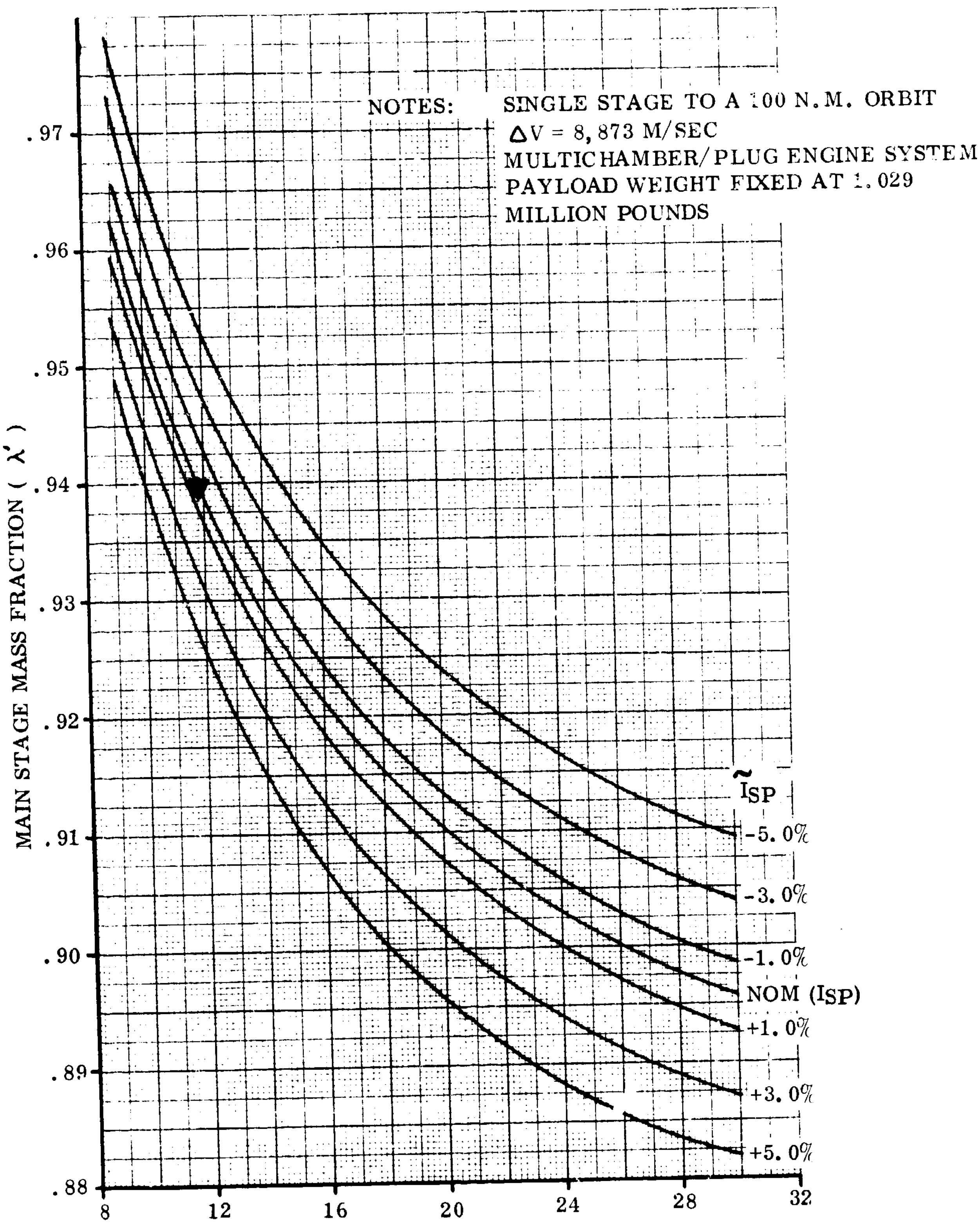

FIGURE 6.1.0.0-1 AMLLV MAIN STAGE - MASS FRACTION VERSUS WEIGHT FOR SINGLE-STAGE-TO-ORBIT VEHICLE

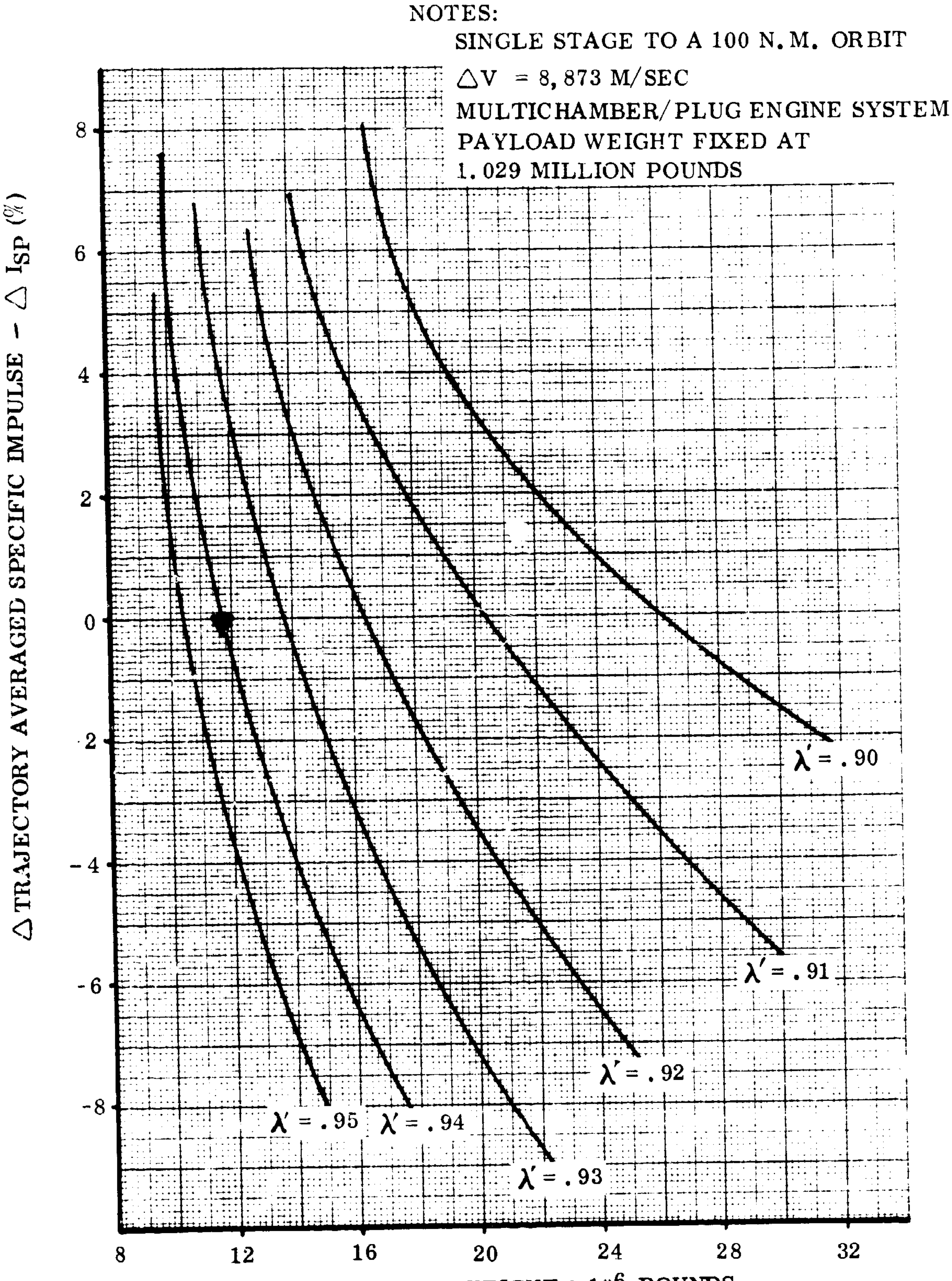

FIGURE 6.1.0.0-2 AMLLV MAIN STAGE - SPECIFIC IMPULSE VERSUS WEIGHT FOR SINGLE-STAGE-TO-ORBIT VEHICLE

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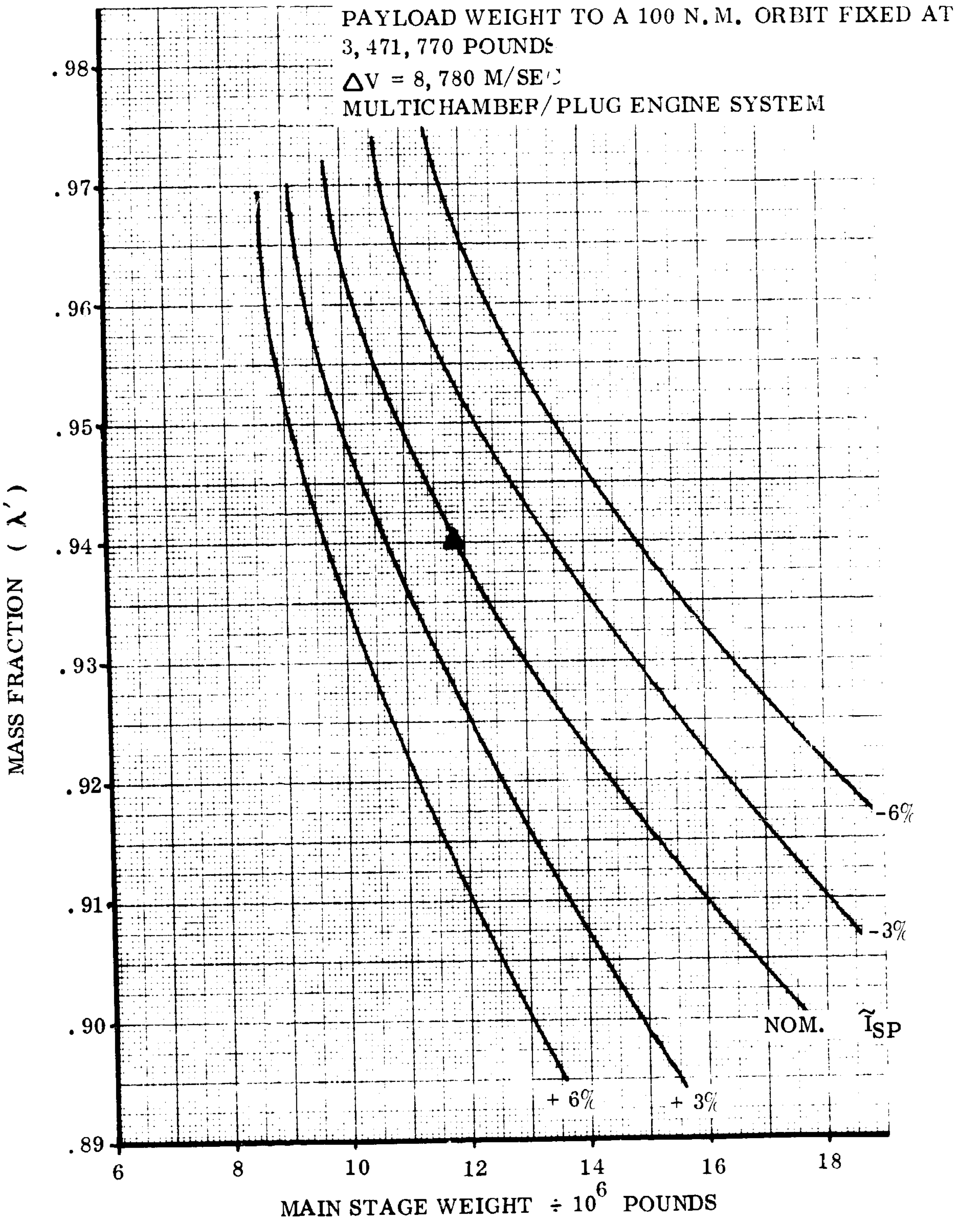


FIGURE 6.1.0.0-3 AMLLV MAIN STAGE - MASS FRACTION VERSUS WEIGHT FOR MAIN STAGE PLUS 12 STRAP-ON STAGES VEHICLE

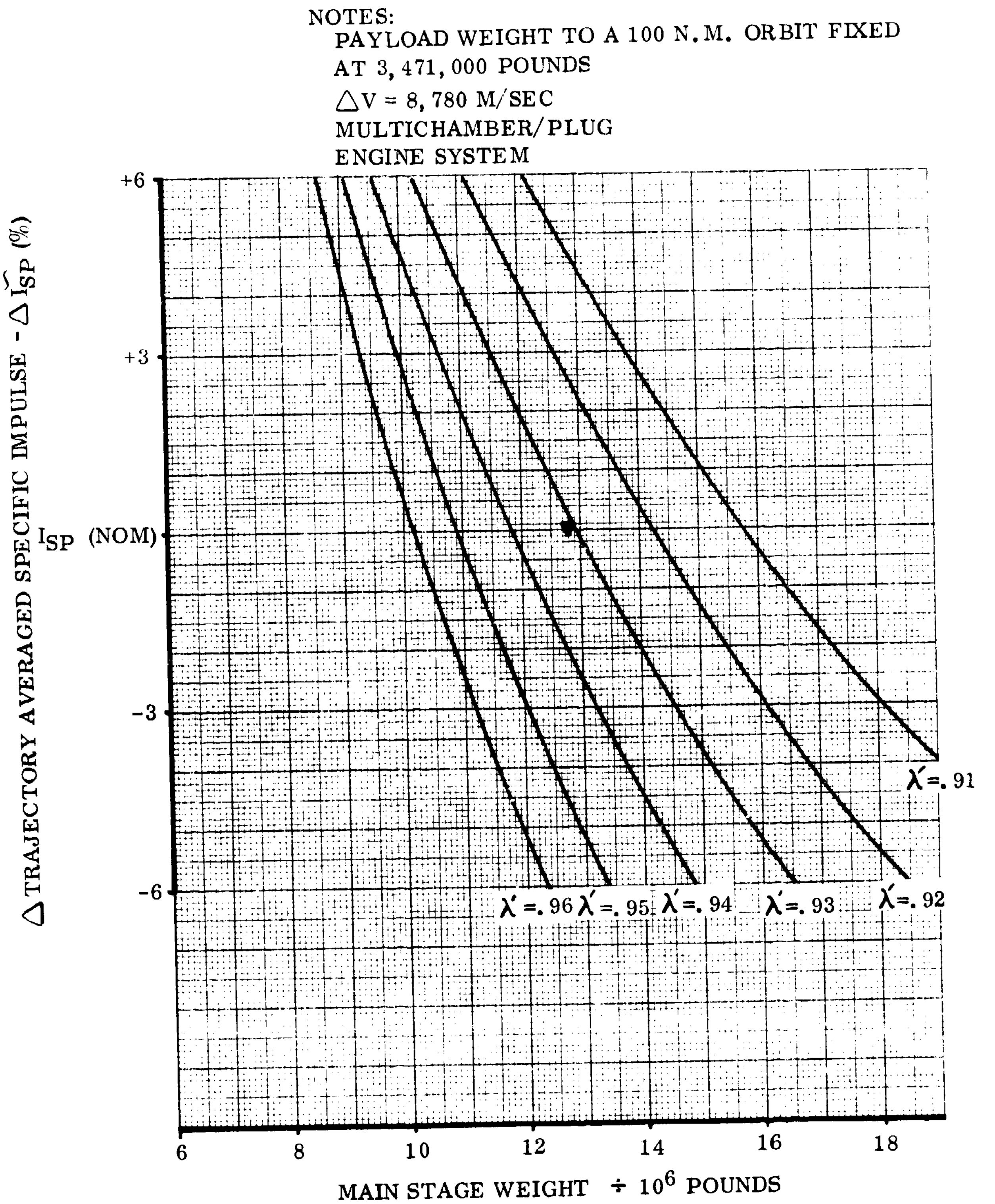


FIGURE 6.1.0.0-4 AMLLV MAIN STAGE - SPECIFIC IMPULSE VERSUS WEIGHT FOR MAIN STAGE PLUS 12 STRAP-ON STAGES VEHICLE

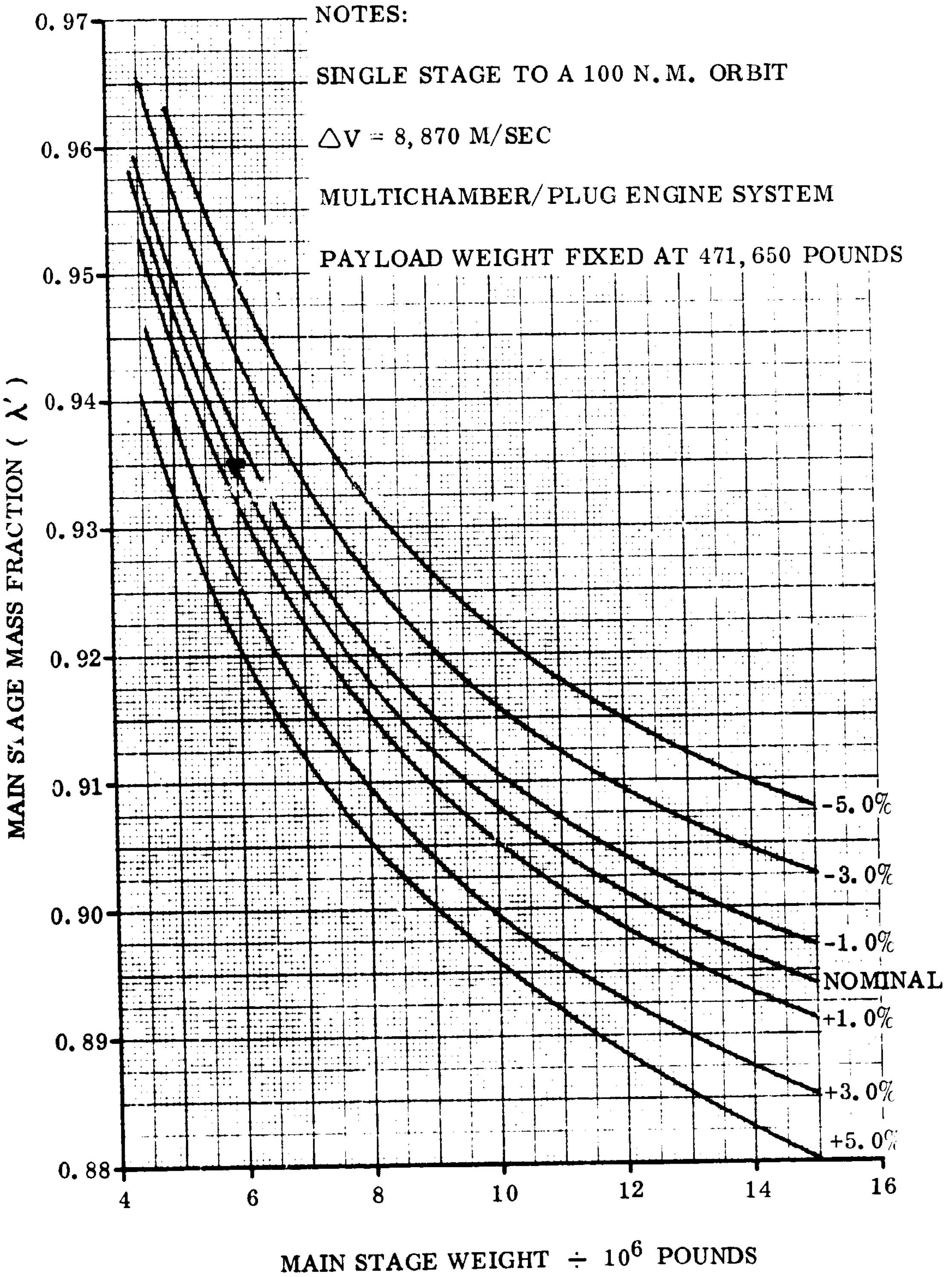


FIGURE 6.1.0.0-5 MLLV MAIN STAGE - MASS FRACTION VERSUS WEIGHT FOR SINGLE-STAGE-TO-ORBIT VEHICLE

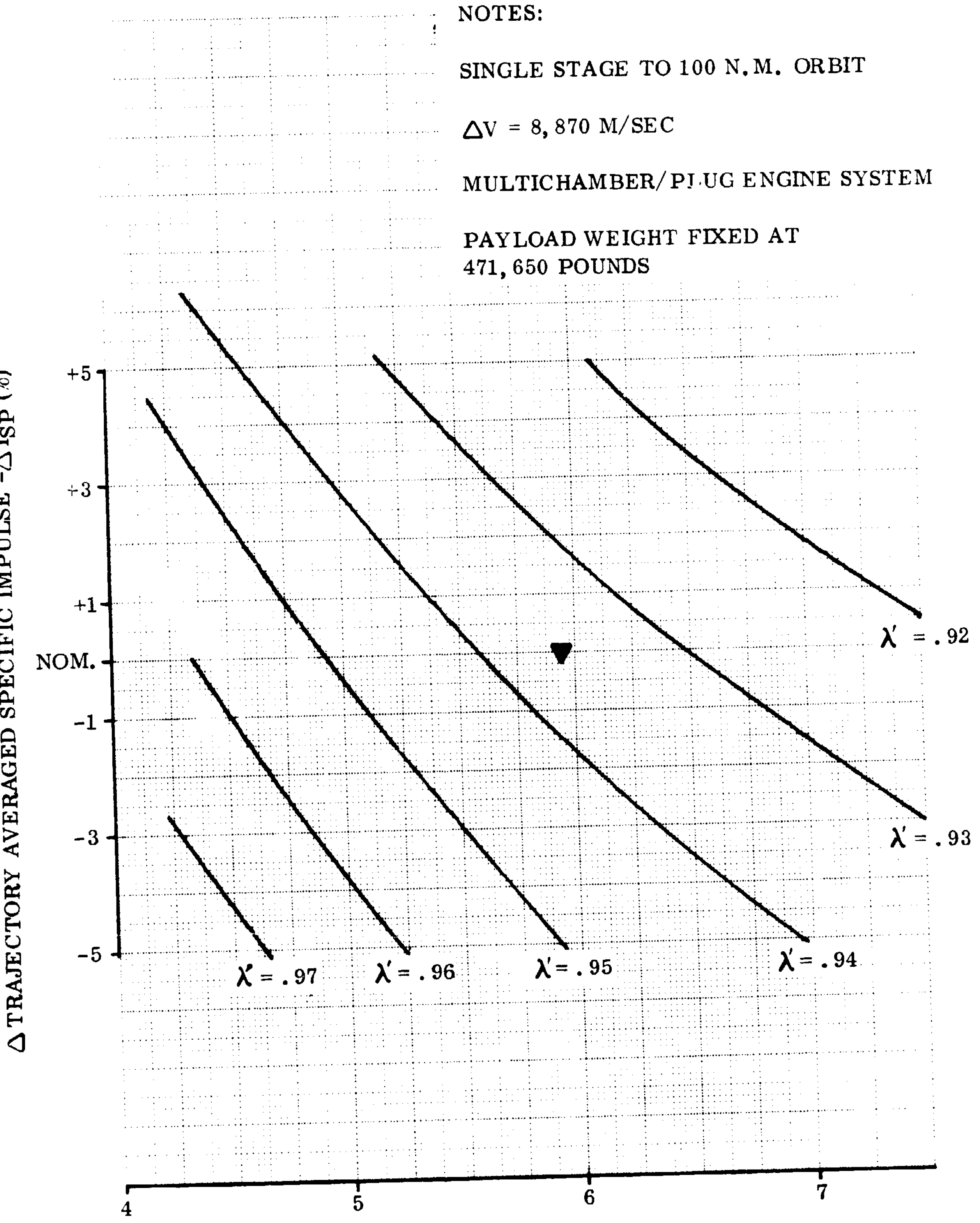


FIGURE 6.1.0.0-6 MLLV MAIN STAGE - SPECIFIC IMPULSE VERSUS WEIGHT FOR SINGLE-STAGE-TO-ORBIT VEHICLE

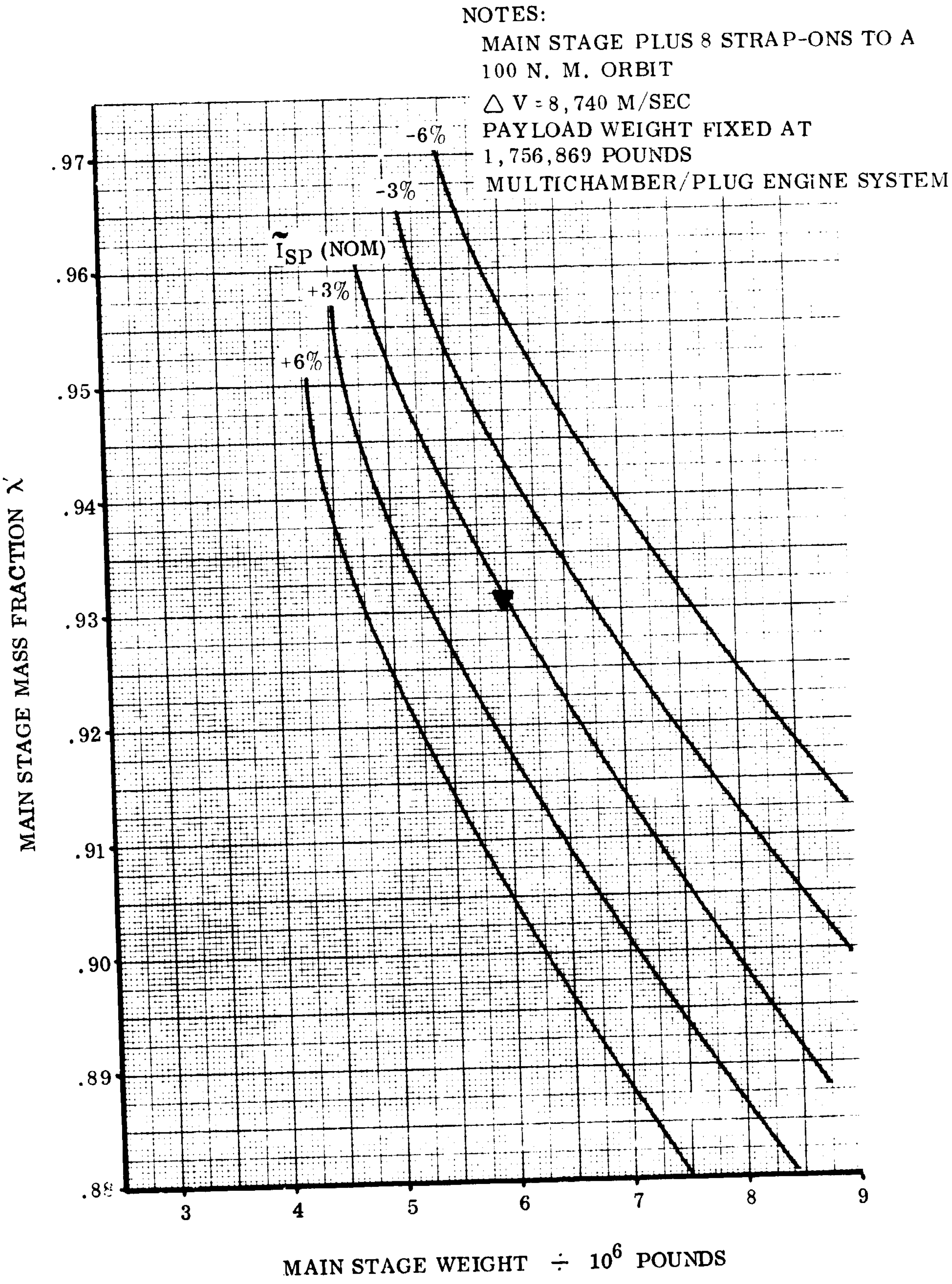


FIGURE 6.1.0.0-7 MLLV MAIN STAGE - MASS FRACTION VERSUS WEIGHT FOR MAIN STAGE PLUS 8 STRAP-ON STAGES VEHICLE

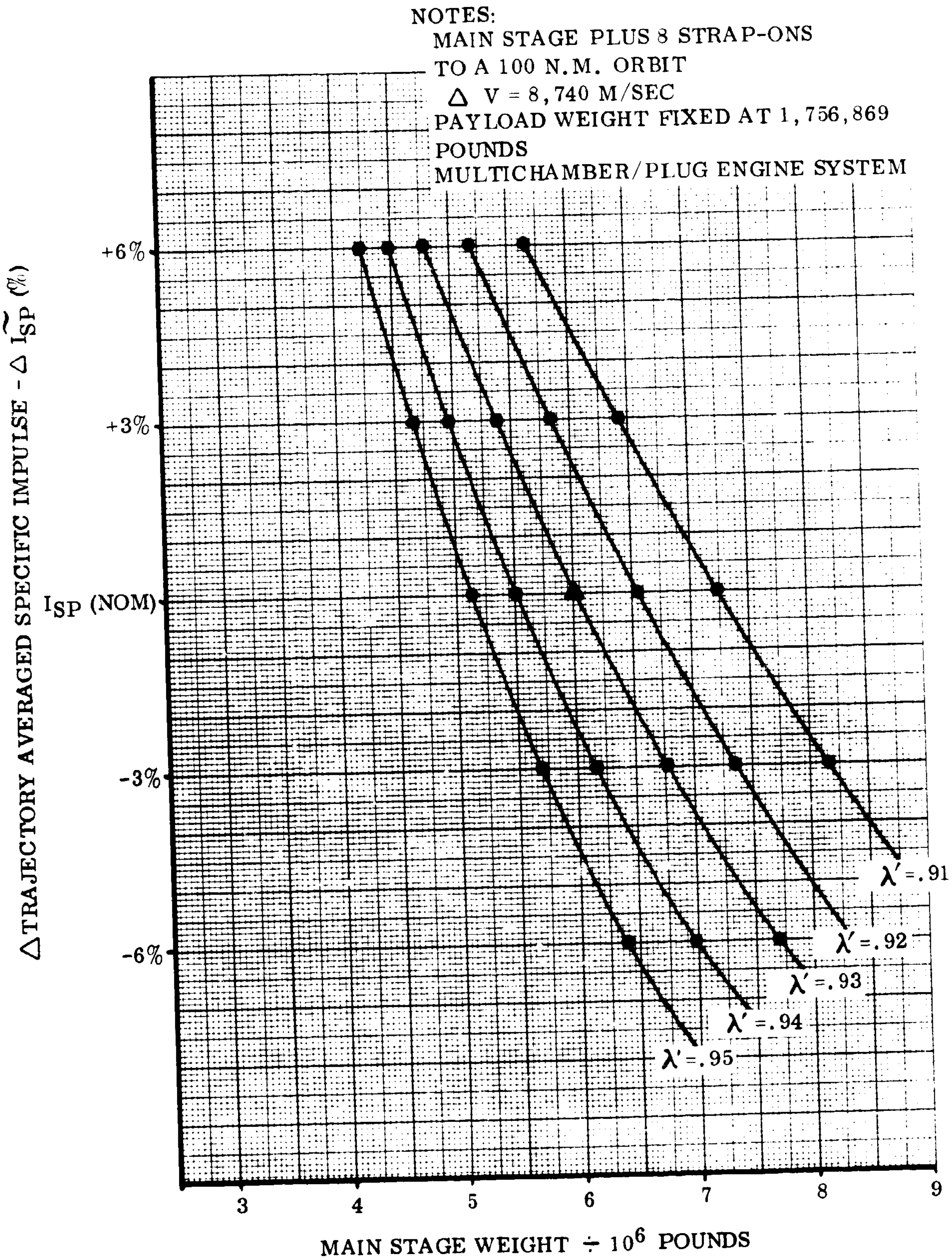


FIGURE 6.1.0.0-8 MLLV MAIN STAGE - SPECIFIC IMPULSE VERSUS WEIGHT FOR MAIN STAGE PLUS 8 STRAP-ON STAGE VEHICLE

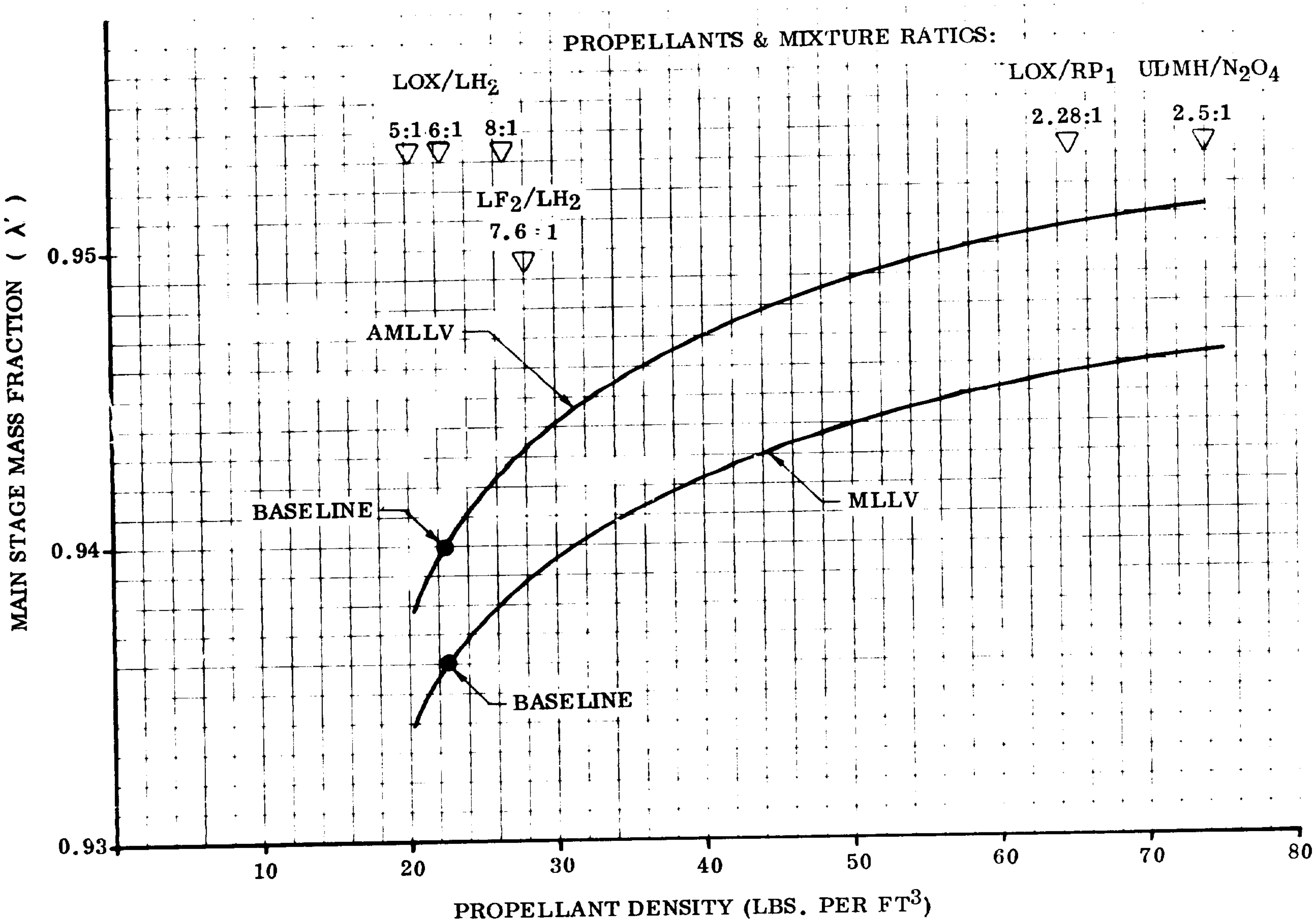


FIGURE 6.1.0.0-9 MAIN STAGE MASS FRACTION VERSUS PROPELLANT DENSITY

6.1 (Continued)

λ' of .94 and the nominal trajectory averaged I_{sp}. This figure shows, for example, that if the λ' is increased from .94 to .95 and the I_{sp} remains constant, the required main stage weight will decrease to 10.4 million pounds.

Figure 6.1.0.0-2 shows the required weight of the AMLLV main stage as a function of trajectory averaged I_{sp} for various values of λ'. The baseline vehicle is again identified by the triangle. If the trajectory averaged I_{sp} is increased by 5% at a constant λ' of 0.94, the required main stage weight will decrease from 11.8 million pounds to 10.0 million pounds.

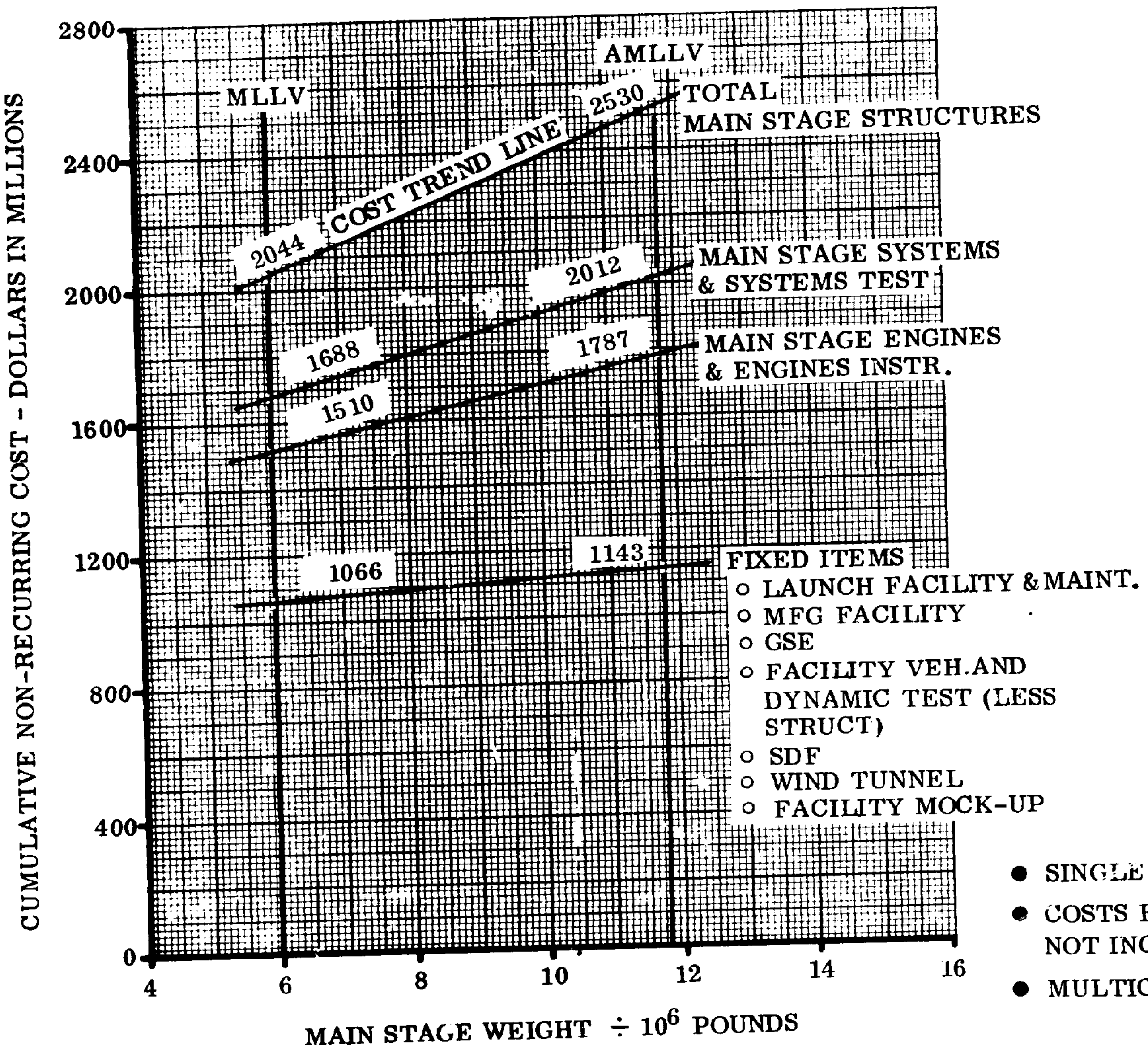
Figures 6.1.0.0-3 and 6.1.0.0-4 show similar relationships for the main stage of the AMLLV main stage plus twelve strap-on stages vehicle configuration. Figures 6.1.0.0-5 through 6.1.0.0-8 show similar relationships for the main stage of the MLLV single-stage-to-orbit vehicle and the main stage of the MLLV main stage plus eight strap-on stages vehicle configurations.

Figure 6.1.0.0-9 shows the effect of propellant density on stage mass fraction. For this analysis the stage thrust and propellant weight were held constant. To prepare the chart, it was assumed that changes in propellant density would effect the length (and weight) of the propellant tank cylindrical sections only. As the propellant density was increased, the required length (and weight) of the cylindrical section was reduced. Mixture ratios for LOX/LH_2, LF_2/LH_2, LOX/RP-1 and $UDMH/N_2O_4$ propellants are shown for reference. This curve used in conjunction with the curves of mass fraction and specific impulse versus main stage launch weight, shown in Figures 6.1.0.0-1 through 6.1.0.0-8, can be used to determine the effects of a change of propellant density (and specific impulse) on the required main stage weight to deliver a specified payload weight to orbit.

6.2 SIZE/COST RELATIONSHIPS

The change in main stage weight as described above is reflected in changes in the weight of the major vehicle systems and subsystems such as structure, engines and propellants and in the size of supporting facilities, equipment and tooling.

Figures 6.2.0.0-1 and 6.2.0.0-2 show the non-recurring ("get ready" and development test) costs for the MLLV and AMLLV single-stage-to-orbit vehicles and for the MLLV and AMLLV main stage plus full complement of strap-on stage vehicles. The lines connecting the cost points show the cost trends relative to main stage weights. Costs for the two R&D flights tests are not included. To aid in application of the methodology defined in the following section 6.3, the costs are grouped by the following categories:



- SINGLE STAGE TO A 100 N.M. ORBIT
- COSTS FOR TWO R&D FLIGHT TESTS NOT INCLUDED
- MULTICHAMBER/PLUG ENGINE SYSTEM

FIGURE 6.2.0.0-1 NON-RECURRING COSTS VERSUS MAIN STAGE WEIGHT

- MAIN STAGE PLUS FULL COMPLEMENT OF SRM STRAP-ON STAGES
- 100 N.M. ORBIT
- COST FOR TWO R&D FLIGHTS NOT INCLUDED
- MULTICHAMBER/PLUG ENGINE SYSTEMS
- SOLID MOTOR SIZES FOR AMLLV AND MLLV FIXED

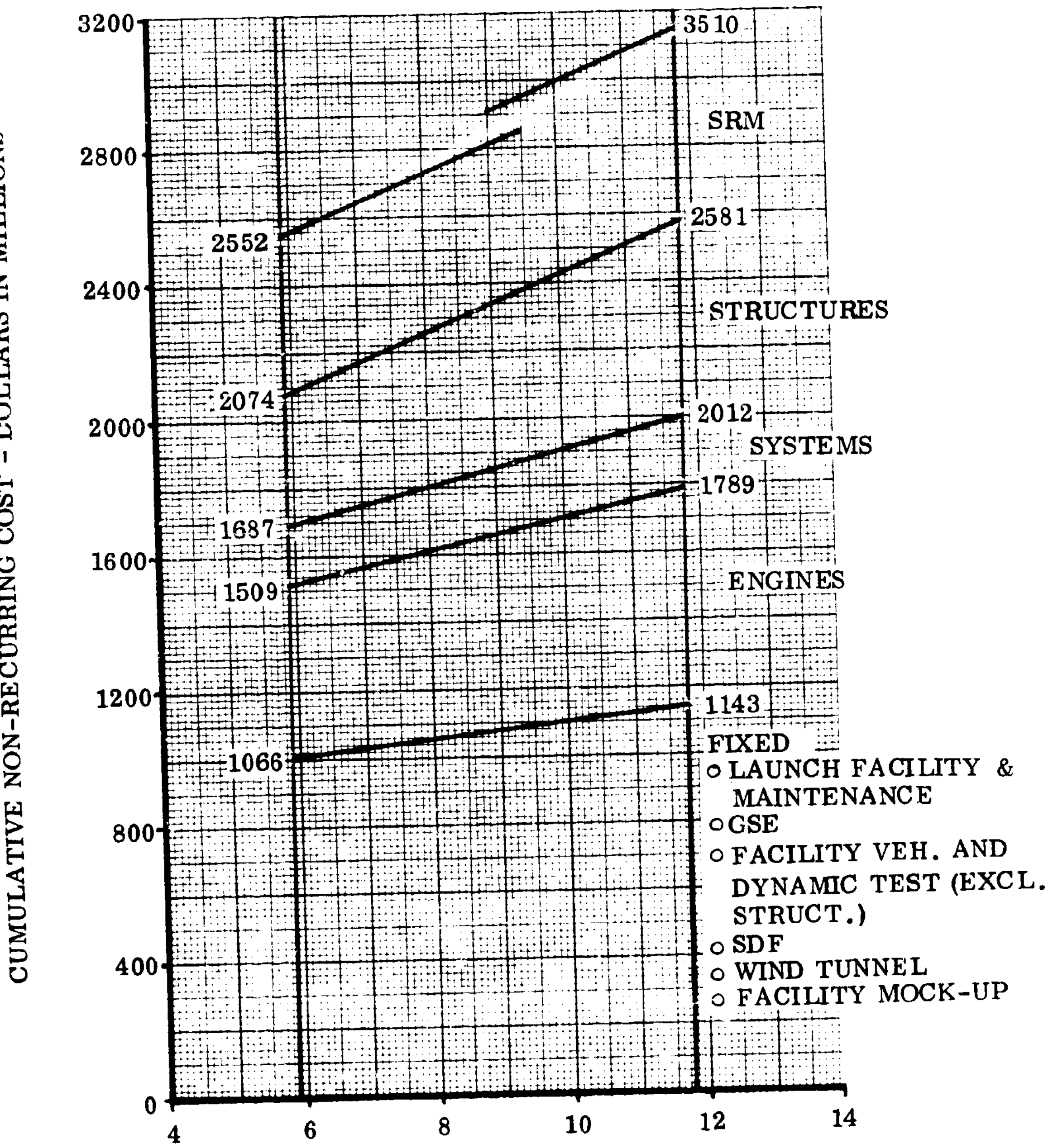


FIGURE 6.2.0.0-2 NON-RECURRING COSTS VERSUS MAIN STAGE WEIGHT

6.2 (Continued)

a. Main Stage Structure - Includes, as applicable to non-recurring or recurring costs, production costs of all main stage structures, structures for Dynamic and Facility Checkout Vehicles, static and dynamic load tests and manufacturing development. Also included (as applicable) are the delta costs for the heavyweight forward skirt.

b. Main Stage System and System Installation - Includes, as applicable to non-recurring or recurring costs, production costs of all main stage systems, system test, system development, and engine installation.

c. Main Stage Engines - Includes, as applicable to non-recurring or recurring costs, production costs of all main stage engines.

d. SRM Strap-On Stages (as applicable) - Includes as applicable to non-recurring or recurring costs, production costs of SRMs structures and motors, SRM GSE, SRM facilities, SRM manufacturing development, SDF, static load, PFRT and wind tunnel.

e. Fixed Costs - Includes launch and manufacturing facilities, transportation, GSE, Systems Breadboard (SDF), SE&I, Instrumentation Unit, wind tunnel tests. manufacturing mockup and propellants.

Similarly, Figures 6.2.0.0-3 through 6.2.0.0-10 show the recurring (production and launch) costs for the MLVV and AMLLV single-stage-to-orbit vehicle configurations and for the MLLV and AMLLV main stage plus full complement of strap-on stage vehicle configurations. The cumulative recurring costs are shown for various program sizes (6, 12, 24, and 36 operational launches plus two R&D flight tests). Learning curve effects are included.

As shown by Figures 6.2.0.0-1 through Figure 6.2.0.0-10, there will be a minimal cost reduction associated with reduction in size for main stage systems and for fixed items such as facilities, launch operations, GSE, etc.

The most appreciable cost/size relationship will be for main stage structure and for main stage engines. The costs of these two elements will reduce by approximately 30% as the vehicle size is reduced from the full size AMLLV to the half size MLLV configuration. The total reduction in cost for this size change will be approximately 19%.

- SINGLE STAGE TO A 100 N.M. ORBIT
- MULTICHAMBER/PLUG ENGINE SYSTEM
- SIX OPERATIONAL LAUNCHES PLUS TWO R&D FLIGHT TESTS

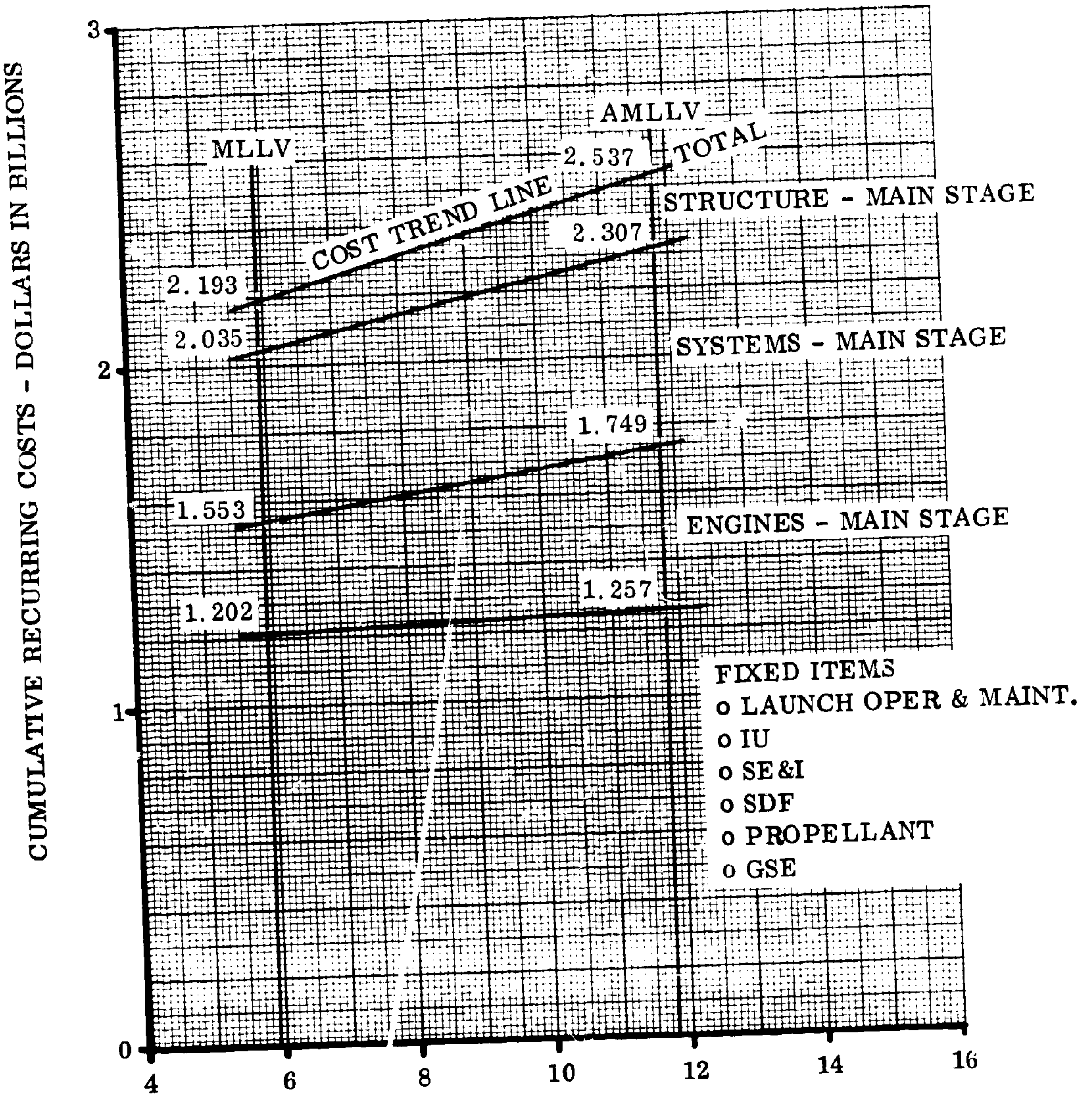


FIGURE 6.2.0.0-3 RECURRING COSTS VERSUS MAIN STAGE WEIGHT

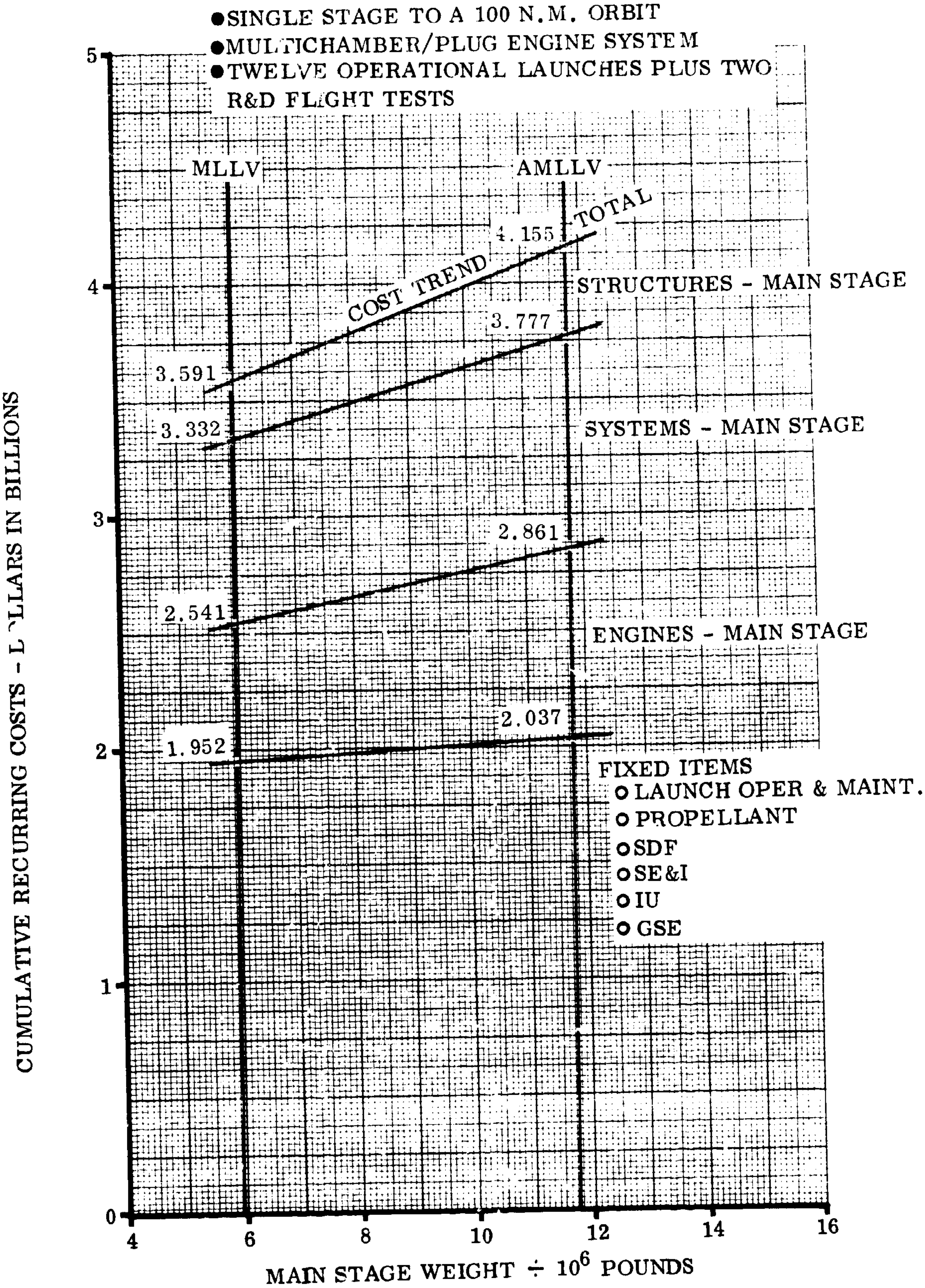


FIGURE 6.2.0.0-4 RECURRING COSTS VERSUS MAIN STAGE WEIGHT

- SINGLE STAGE TO A 100 N.M. ORBIT
- MULTICHAMBER/PLUG ENGINE SYSTEM
- 24 OPERATIONAL LAUNCHES PLUS TWO R&D FLIGHTS

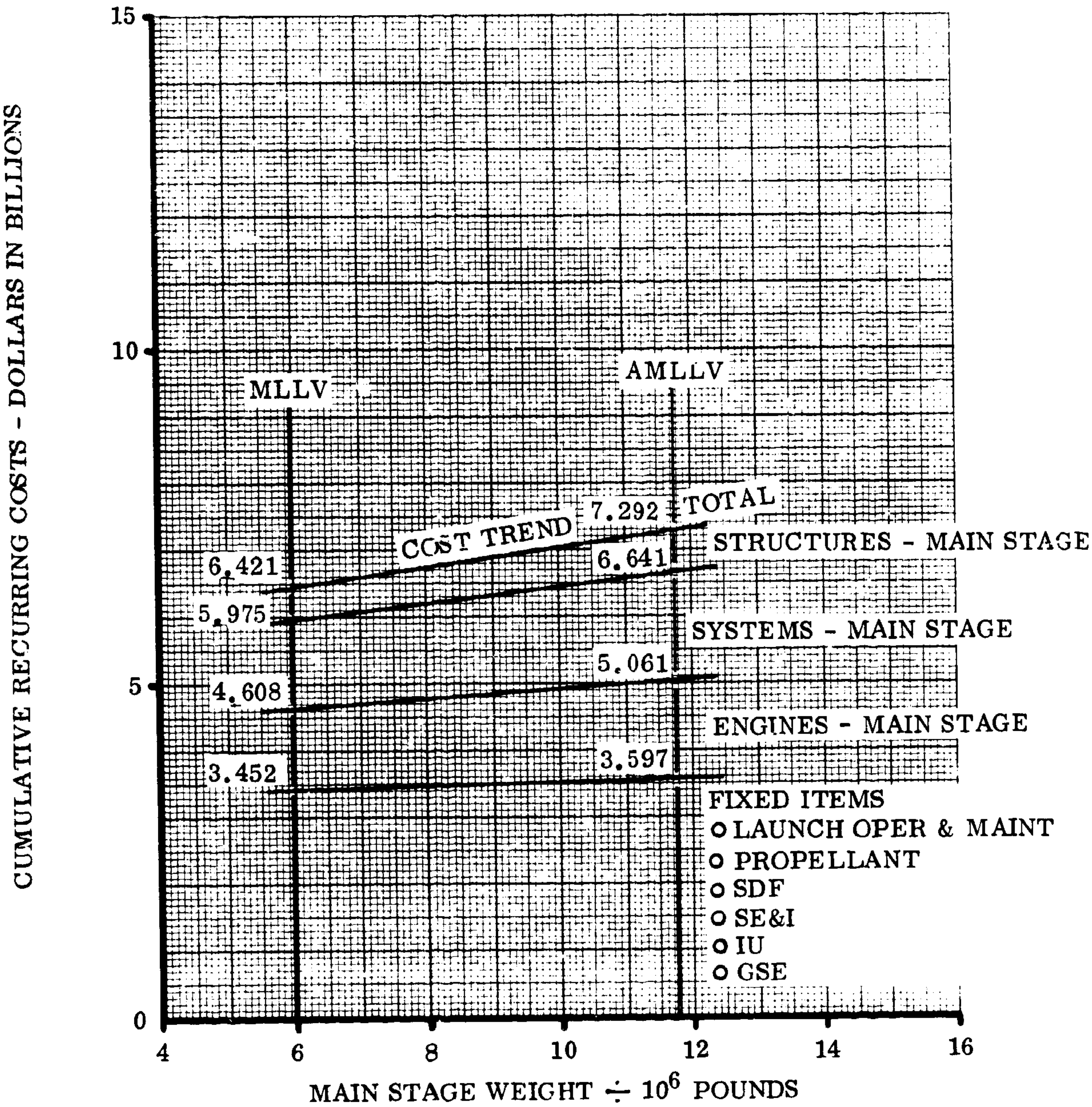
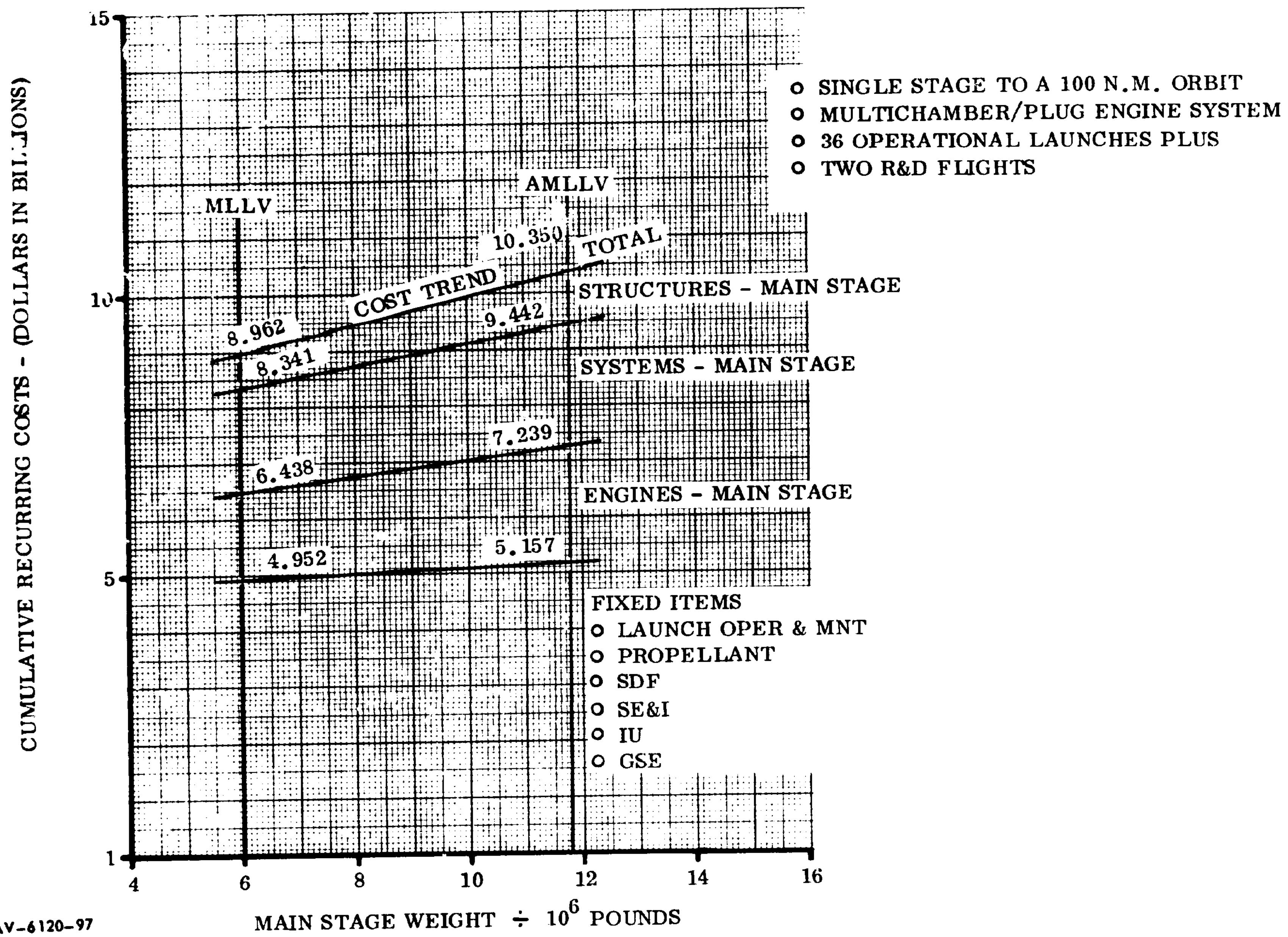


FIGURE 6.2.0.0-5 RECURRING COSTS VERSUS MAIN STAGE WEIGHT


15
10
5
1
4
6
8
10
12
14
16
CUMULATIVE RECURRING COSTS - (DOLLARS IN BILLIONS)
MAIN STAGE WEIGHT ÷ 10^6 POUNDS
MLLV
AMLLV
10.350
TOTAL
COST TREND
8.962
8.341
9.442
STRUCTURES - MAIN STAGE
SYSTEMS - MAIN STAGE
6.438
7.239
ENGINES - MAIN STAGE
4.952
5.157
O SINGLE STAGE TO A 100 N.M. ORBIT
O MULTICHAMBER/PLUG ENGINE SYSTEM
O 36 OPERATIONAL LAUNCHES PLUS
O TWO R&D FLIGHTS
FIXED ITEMS
O LAUNCH OPER & MNT
O PROPELLANT
O SDF
O SE&I
O IU
O GSE

AV-6120-97

- MAIN STAGE PLUS FULL COMPLEMENT OF SRM STRAP-ON STAGES
- 100 N.M. ORBIT
- MULTICHAMBER/PLUG ENGINE SYSTEM
- SIX OPERATIONAL LAUNCHES PLUS TWO R&D FLIGHTS
- SOLID MOTOR SIZES FOR AMLLV AND MLLV FIXED

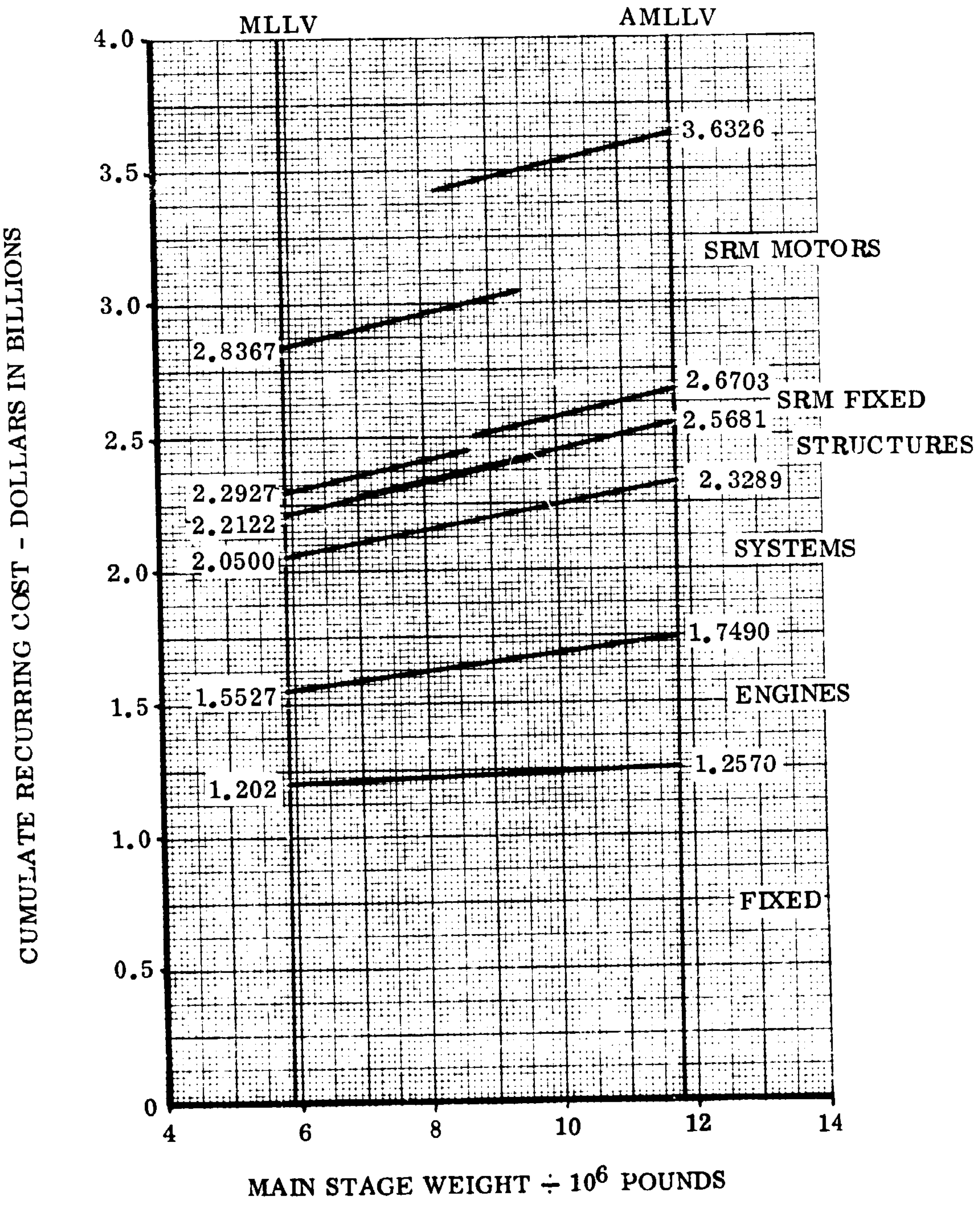


FIGURE 6.2.0.0-7 RECURRING COST VERSUS MAIN STAGE WEIGHT

- MAIN STAGE PLUS FULL COMPLEMENT OF SRM STRAP-ON STAGES
- 100 N.M. ORBIT
- MULTICHAMBER/PLUG ENGINE SYSTEM
- TWELVE OPERATIONAL LAUNCHES PLUS TWO R&D FLIGHTS
- SOLID MOTOR SIZES FOR AMLLV AND MLLV FIXED

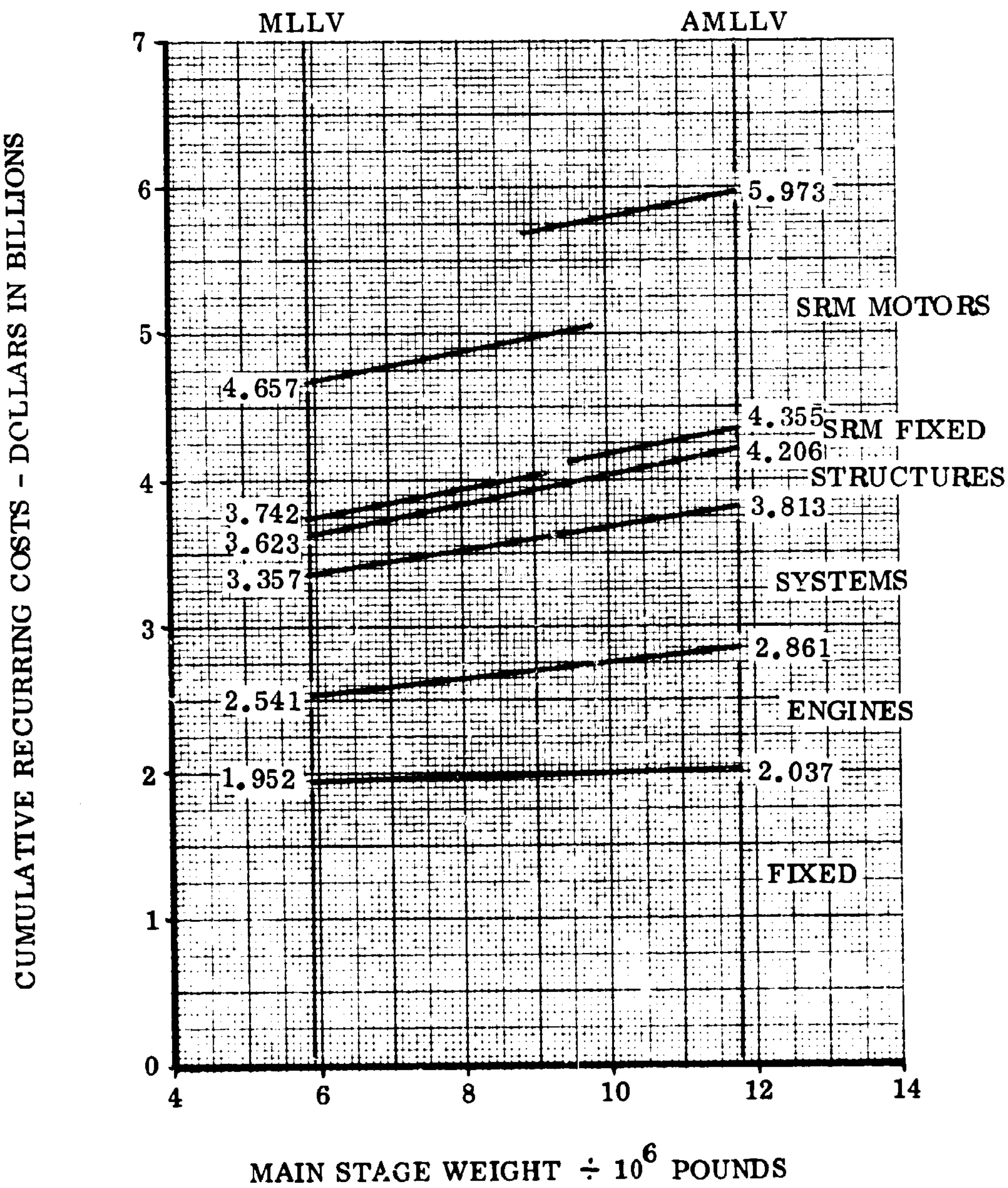


FIGURE 6.2.0.0-8 RECURRING COST VERSUS MAIN STAGE WEIGHT

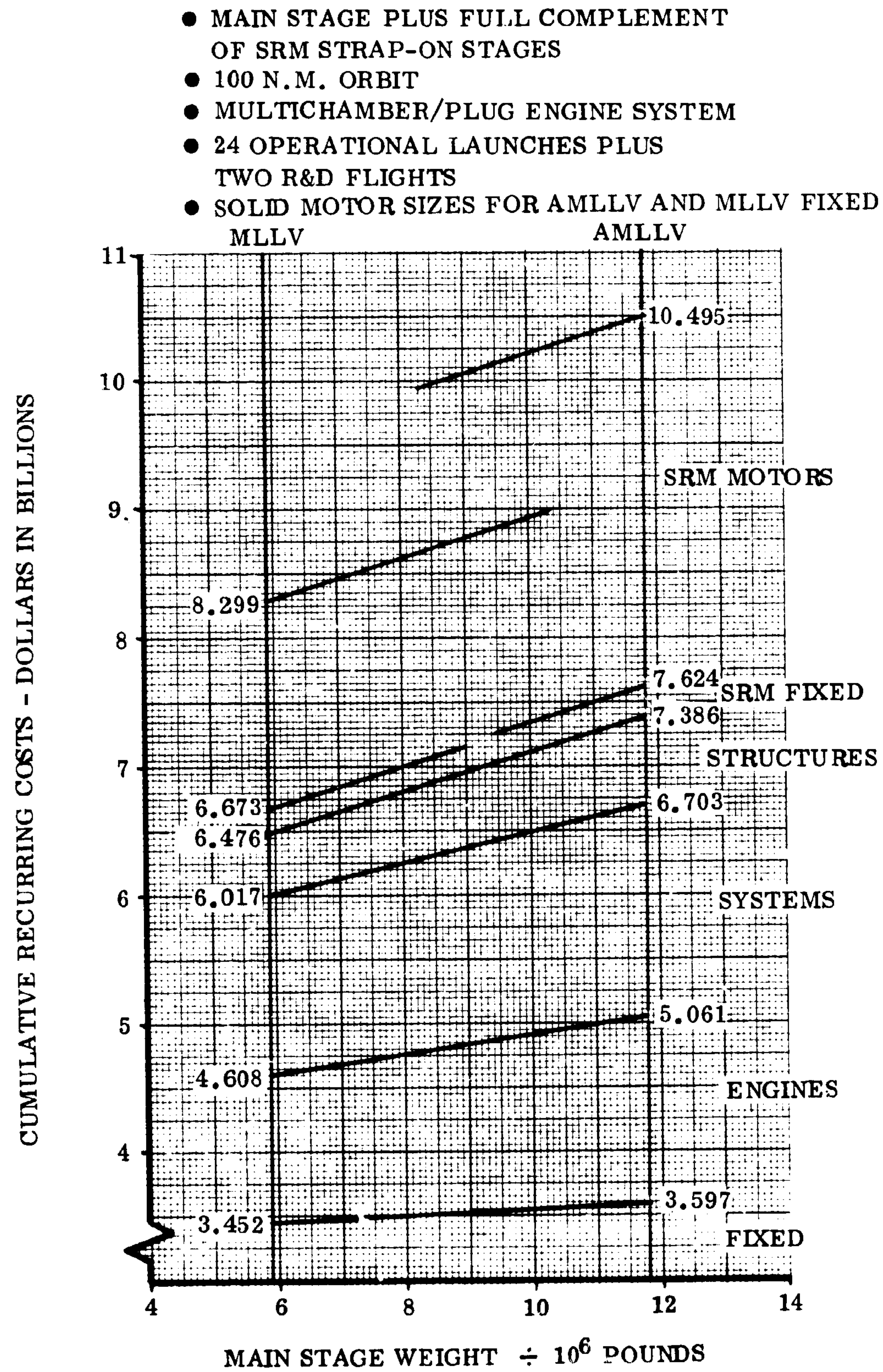


FIGURE 6.2.0.0-9 RECURRING COSTS VERSUS MAIN STAGE WEIGHT

- MAIN STAGE PLUS FULL COMPLEMENT OF SRM STRAP-ON STAGES
- 100 N.M. ORBIT
- MULTICHAMBER/PLUG ENGINE SYSTEM
- 36 OPERATIONAL LAUNCHES PLUS TWO R&D FLIGHTS
- SOLID MOTOR SIZES FOR AMLLV AND MLLV FIXED

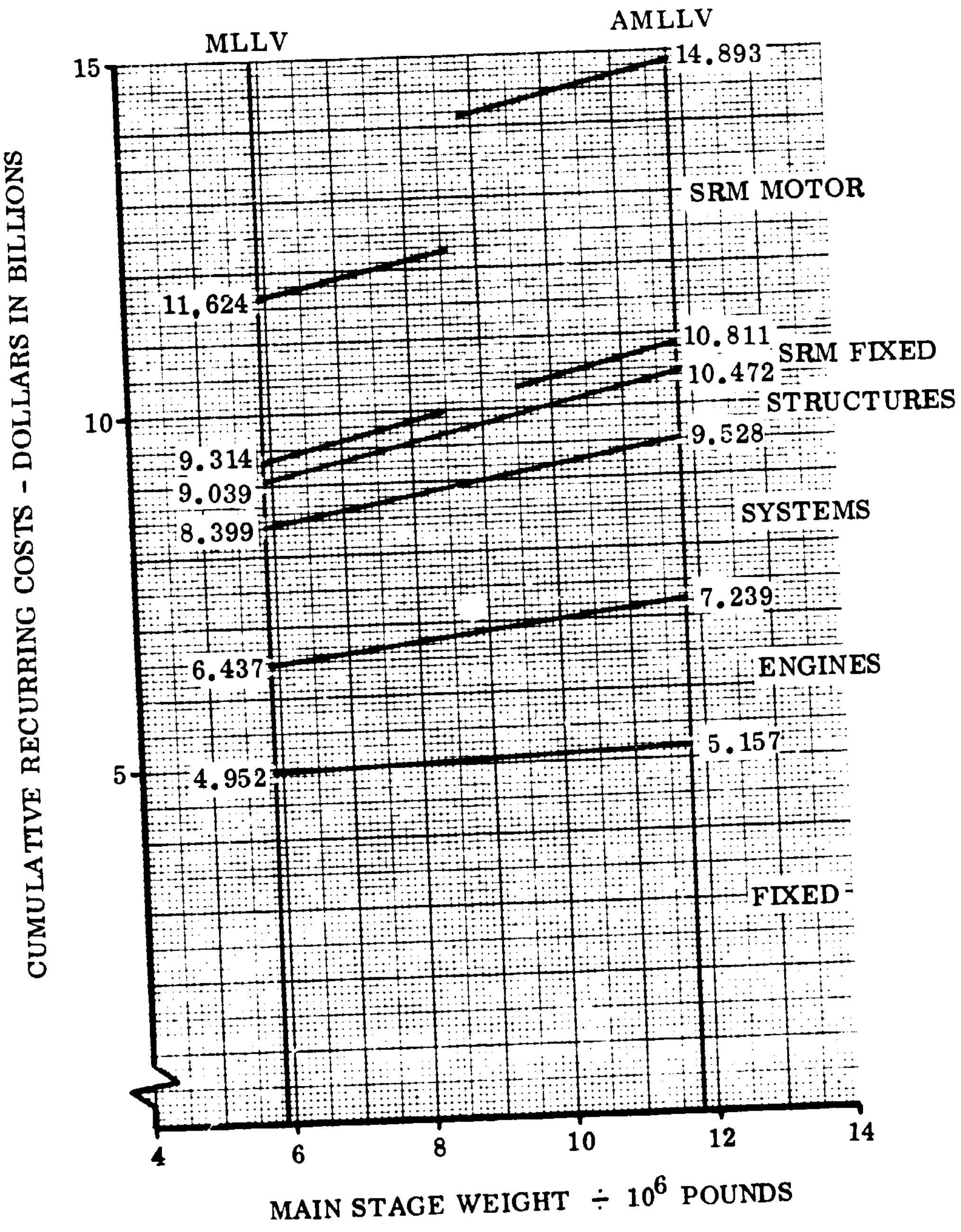


FIGURE 6.2.0.0-10 RECURRING COSTS VERSUS MAIN STAGE WEIGHT

6.3 METHODOLOGY FOR COST EFFECTIVENESS EVALUATIONS

The preceding Figures 6.1.0.0-1 through 6.1.0.0-9 show the effect of technology variables on main stage weight. These data plus the cost versus size data from the preceding Figures 6.2.0.0-1 through 6.2.0.0-10 provide the required input data for evaluating the cost effectiveness of alternative technology applications to the primary stage of the baseline MLLV and AMLLV families. The following representative examples show the methodology for applying this data.

6.3.1 Effects on Cost of Changes in Main Stage Mass Fraction

A representative example of the methodology for application of this data for evaluation of alternative structure is shown in Figure 6.3.1.0-1. This figure shows the maximum dollars, for R&D and a 36 AMLLV single stage to orbit production and launch program, which can be expended for R&D and for production of the advanced structure alternative (to replace the structure specified for the baseline vehicle) without increasing the overall program cost.

For this particular example, the following conditions were considered or assumed:

a. Vehicle: AMLLV single-stage-to-orbit vehicle - Main stage weight = 11.805×10^6 lbs.

b. Program Size: 36 launches @ 1,029,000 pounds of payload per launch.

c. System Investigated: Structures

d. Technology change: Change in mass fraction from $\lambda' = .94$ to $\lambda' = .95$.

The procedure was as follows:

a. The total cumulative AMLLV non-recurring cost of $2.53 billion was determined from Figure 6.2.0.0-1.

b. The total cumulative AMLLV recurring cost of $10.35 billion was determined from Figure 6.2.0.0-6.

c. These costs (a and b above) were added to determine the total accumulative costs of $12.88 billion. (Plot point "A" in Figure 6.3.1.0-1).

d. The structure system cost was determined from Figure 6.2.0.0-1 and 6.2.0.0-6 as in steps a, b, and c above to be $1.46 billion.

- AMLLV SINGLE-STAGE TO A 100 N.M. EARTH ORBIT
- MULTICHAMBER/PLUG ENGINE SYSTEM
- PROGRAM - 36 OPERATIONAL LAUNCHES
- CHANGE IN λ' FROM 0.94 TO 0.95

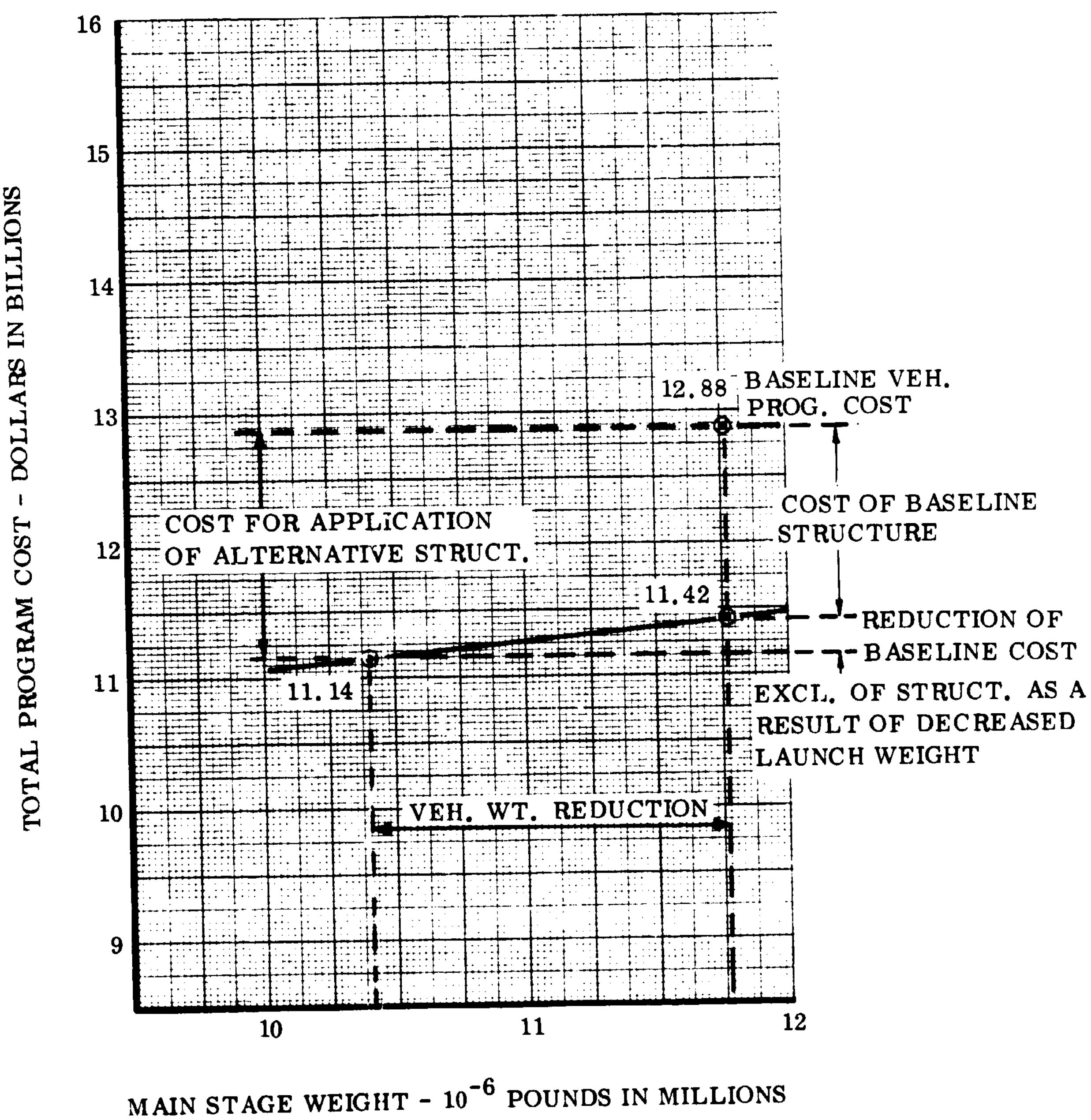


FIGURE 6.3.1.0-1 COST EFFECTIVENESS EVALUATION OF ALTERNATIVE STRUCTURE TECHNOLOGY

6.3.1 (Continued)

e. The total baseline program cost (excluding structures) was determined to be \$11.42 billion (Plot point B in Figure 6.3.1.0-1) by subtracting step (d) from step (c).

f. From Figure 6.1.0.0-1, using a λ' of 0.95 and the nominal trajectory averaged I_{sp}, the new AMLLV main stage weight of 10.4×10^6 lbs. was determined.

g. From Figure 6.2.0.0-1 and 6.2.0.0-6, the total cumulative program costs (excluding structure) for the new vehicle weight was determined to be \$11.14 billion (Plot point "C" in Figure 6.3.1.0-1).

Points A, B and C as derived by the above technique and plotted in Figure 6.3.1.0-1 formed the cost effectiveness parameters of the alternative structural technology to be investigated. The line connecting points B and C is the cost reduction line; the slope of which indicates the degree of cost reduction relative to size of the main stage. (The steeper this slope,the more cost reduction will be realized.)

The cost difference between points B and C of \$280 million is the amount that the total program costs, (exclusive of the cost of structures) for a program of 36 launches, will be reduced as a result of a decrease in vehicle launch weight due to a change in mass fraction from $\lambda' = .94$ to $\lambda' = .95$. The cost difference between points A and B of \$1,460 million is the sum of the non-recurring and recurring cost of the old structure to be replaced.

The total cost difference between points A and C is \$1,720 million which is then the maximum amount which can be expended for development and application of the alternative structures if they are to be cost effective. The cost for developing and producing of the alternative structures should, therefore, not exceed the \$1,720 million, otherwise, the new technology will not be economically feasible and should warrant no further in-depth consideration.

Through the use of data presented in Figure 6.1.0.0-1 through 6.1.0.0-9 and Figures 6.2.0.0-1 through 6.2.0.0-10, other similar analyses were conducted for other vehicle configurations and other program sizes. The results of these other analyses are shown in Table 6.3.1.0-1 and Figure 6.3.1.0-2.

Table 6.3.1.0-1 shows: 1) the cost reduction due to size reduction for improved structure (excluding the cost of the baseline structures), 2) the cost of the baseline structure and 3) the total dollars available for replacement of the old baseline structural technology (cost reduction due to size reduction excluding cost of structures plus cost of the baseline structure). Cost data are

NOTES:

- MULTICHAMBER/PLUG ENGINE SYSTEM
- PAYLOAD TO A 100 N. M. EARTH ORBIT
- CHANGE IN $\lambda' = +0.01$

LEGEND:

A = AMLLV SINGLE-STAGE-TO-ORBIT
A+ = AMLLV MAIN STAGE PLUS 12 SRMs
M = MLLV SINGLE-STAGE-TO-ORBIT
M+ = MLLV MAIN STAGE PLUS 8 SRMs

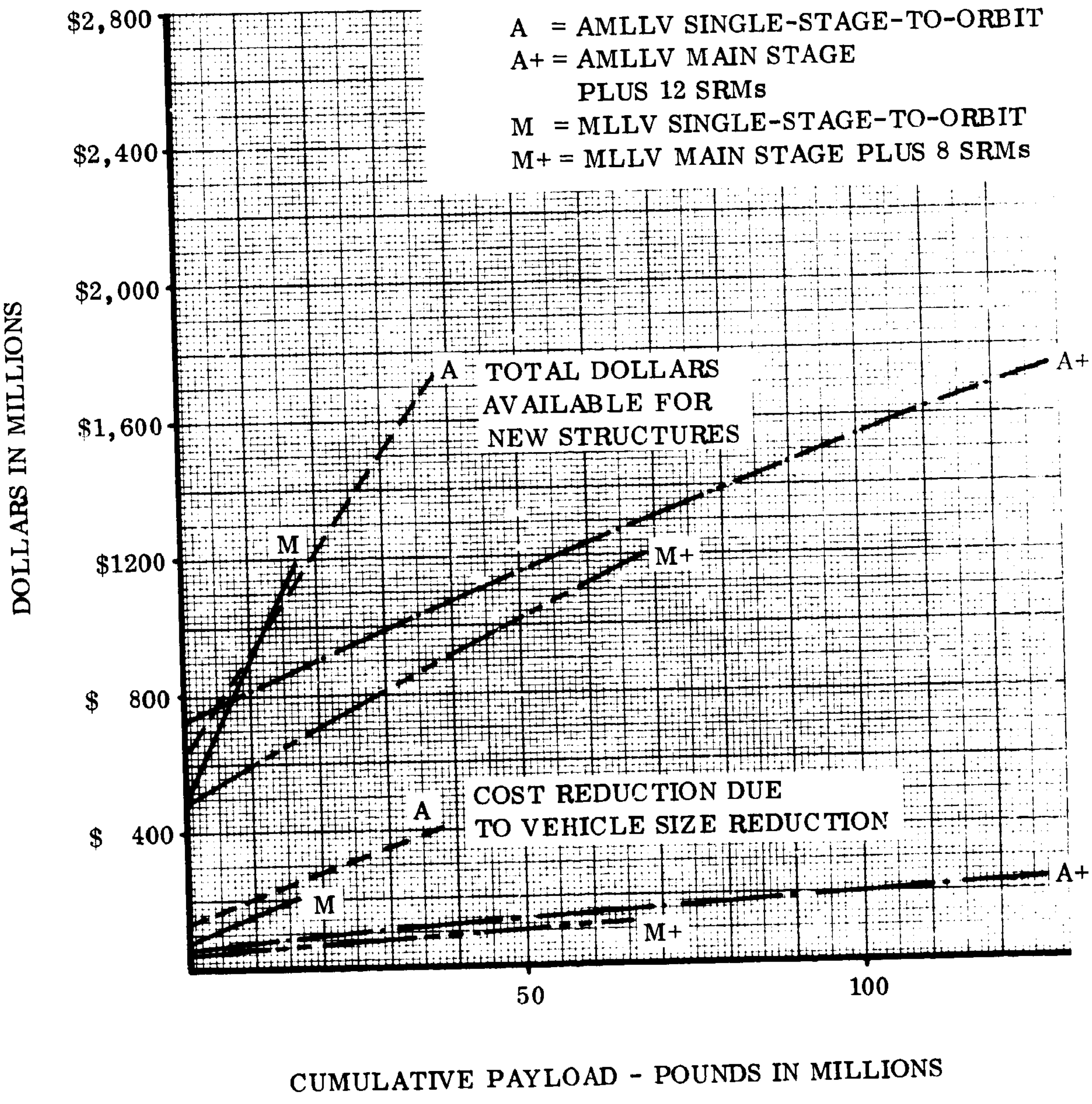


FIGURE 6.3.1.0-2 COST IMPLICATIONS OF A 0.01 IMPROVEMENT IN MASS FRACTION

TABLE 6.3.1.0-I COST IMPLICATIONS OF A 0.01 IMPROVEMENT IN MAIN STAGE MASS FRACTION

	NO. OF OPER. FLTS.	MLLV SINGLE-STAGE-TO-ORBIT		AMLLV SINGLE-STAGE-TO-ORBIT		MLLV MAIN STAGE + 8 SRM's		AMLLV MAIN STAGE + 12 SRM's	
		$ IN BILLIONS	%	$ IN BILLIONS	%	$ IN BILLIONS	%	$ IN BILLIONS	%
Cost Reduction Due to Size Reduction									
Phases A & B	NA	0.057	2.8	0.108	4.3	0.034	1.3	0.064	2.0
Phase C	6	0.036	1.7	0.069	2.7	0.022	0.8	0.041	1.1
(Includes 2	12	0.060	1.7	0.113	2.7	0.036	0.8	0.067	1.1
R&D Flts.)	24	0.109	1.7	0.196	2.7	0.066	0.8	0.117	1.1
(Excludes Cost	36	0.149	1.7	0.280	2.7	0.090	0.8	0.157	1.1
of Structures)									
Cost of Baseline Structure									
Phases A & B	NA	0.356	17.3	0.424	16.7	0.387	15.1	0.569	18.1
Phase C	6	0.158	7.2	0.230	9.1	0.162	5.7	0.239	6.6
(Includes 2	12	0.259	7.2	0.378	9.1	0.266	5.7	0.393	6.6
R&D Flts.)	24	0.446	7.0	0.651	8.9	0.459	5.5	0.677	6.4
	36	0.621	7.0	0.908	8.8	0.640	5.5	0.944	6.3
Total Dollars Available for New Technology									
Phases A, B & C	6	0.607	14.3	0.831	16.4	0.605	8.9	0.913	16.9
	12	0.732	13.0	1.023	15.3	0.723	7.9	1.093	15.2
	24	0.968	11.4	1.353	13.8	0.946	6.9	1.427	13.2
	36	1.183	10.7	1.720	13.3	1.151	6.4	1.734	12.3

6.3.1 (Continued)

shown for Phases A and B (less flight tests) and operational programs of 6, 12, 24, and 36 (plus two flight tests each). The vehicles for which data are depicted are the MLLV single-stage-to-orbit vehicle, the MLLV main stage plus 8 SRMs vehicle, the AMLLV single-stage-to-orbit vehicle and the AMLLV main stage plus 12 SRMs vehicle. This table is somewhat difficult to interpret because of the large variance in payloads between the various vehicle sizes. For example, 36 flights of the MLLV single-stage-to-orbit vehicle will deliver something less than 18 million pounds to orbit while 36 flights of the AMLLV main stage plus 12 SRMs vehicle will deliver 144 million pounds of payload to orbit.

Figure 6.3.1.0-2 was prepared to provide better visibility of the dollars available for new technology (for a 0.01 improvement in the main stage mass fraction) relative to comparative payload programs. This figure shows the overall program cost reduction due to vehicle size reduction and the total dollars available within the program for new structure to provide an improvement in main stage mass fraction of 0.01. This figure shows that the single-stage-to-orbit vehicles are more sensitive to technology improvements, i.e., more cost reduction can be realized with the single-stage-to-orbit vehicles through technology improvements than for the vehicles consisting of main stages plus a full complement of strap-on stages. For a smaller program which requires a few pounds of payload to orbit, Figure 6.3.1.0-2 indicates that the larger (AMLLV) vehicles will have more dollars available for new structures technology than will the smaller (MLLV) vehicles. However, this chart further indicates, that for larger payload programs, the smaller (MLLV) vehicles will have more dollars available for new structures technology. (The tabulated data on 6.3.1.0-1 explains why this is so. The cost savings attributable to technology changes for the AMLLV type vehicles during the A and B phases will be considerably larger than the cost savings attributable to those on the MLLV vehicles. Conversely, the size reduction resulting from alternative structure applications and the cost of the baseline structures will result in more available recurring dollars per pound of delivered payload for the MLLV vehicles than for the AMLLV vehicles.)

The data discussed above relates only to an improvement in main stage mass fraction of 0.01 through the replacement of the baseline structure with an alternative advanced technology type structure. Similar trades can be performed to define the dollars available for other values of main stage mass fraction attributable to structural changes or to weight changes in engine systems, subsystems, etc. The same methodology as described above would be used.

To provide a better understanding of the cost implications of mass fraction, Figures 6.3.1.0-3 through 6.3.1.0-5 are provided. These figures show the

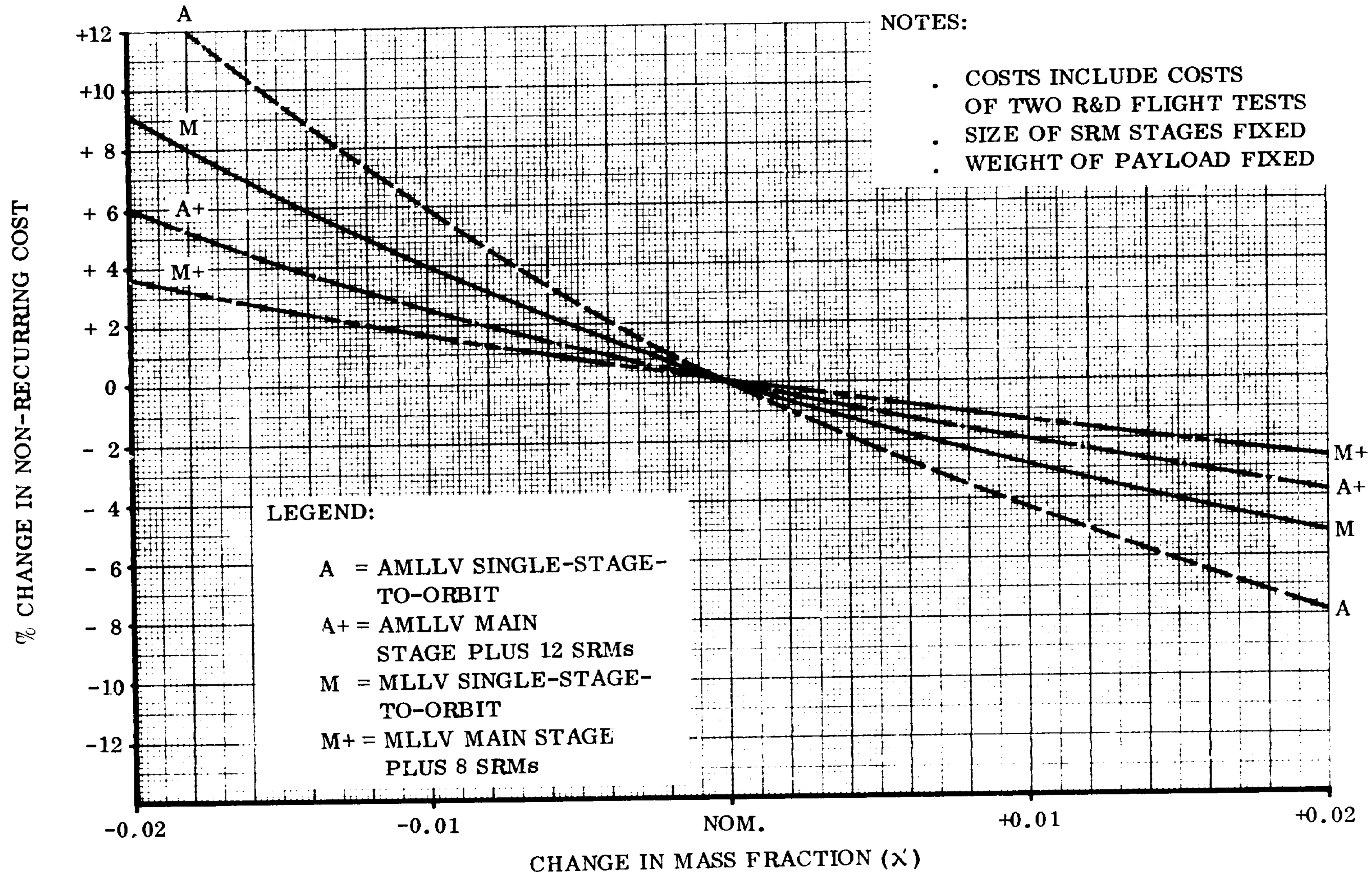


FIGURE 6.3.1.0-3 SENSITIVITY OF NON-RECURRING COSTS TO MAIN STAGE MASS FRACTION

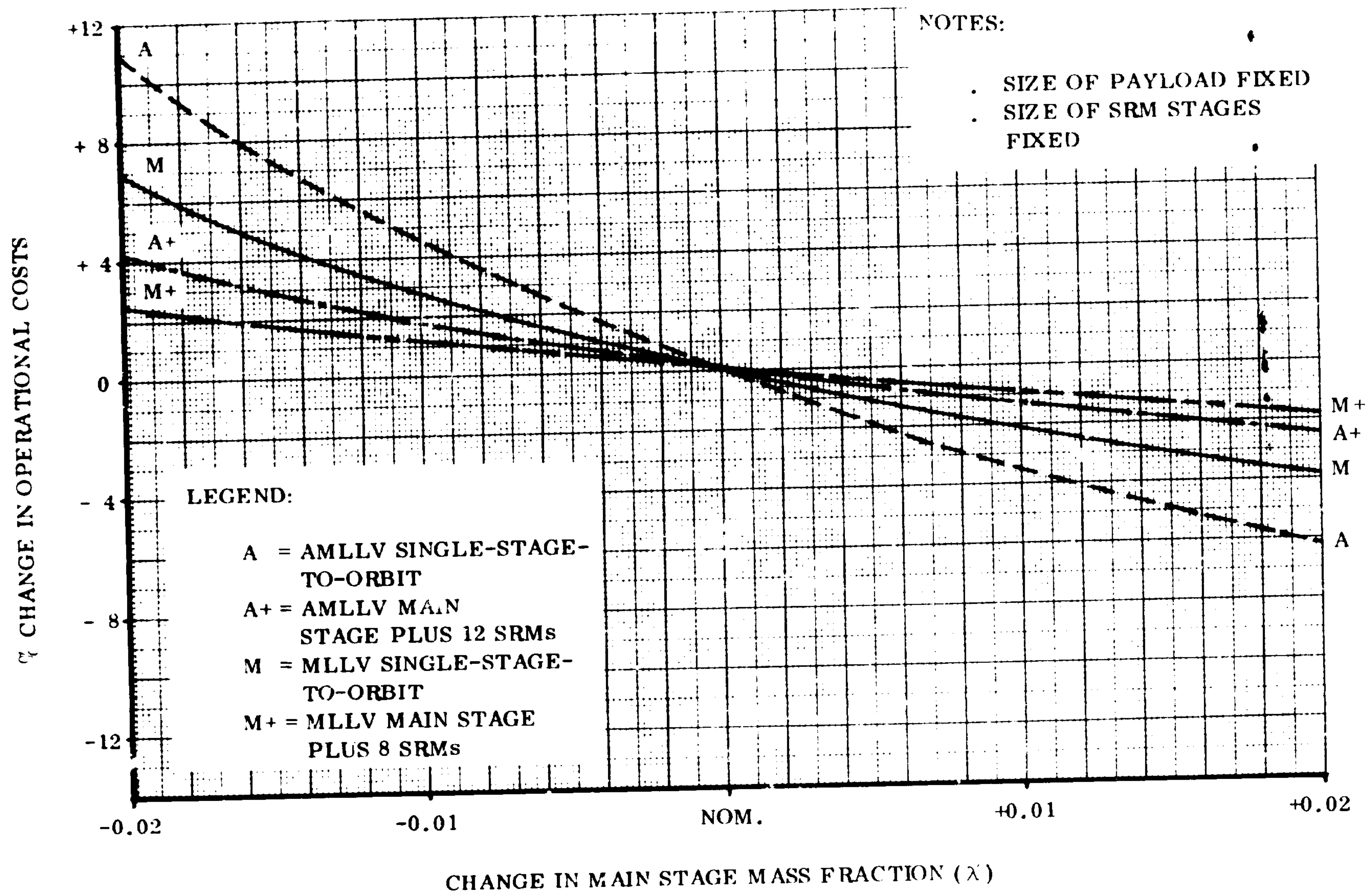


FIGURE 6.3.1.0-4 SENSITIVITY OF RECURRING COSTS TO MAIN STAGE MASS FRACTION

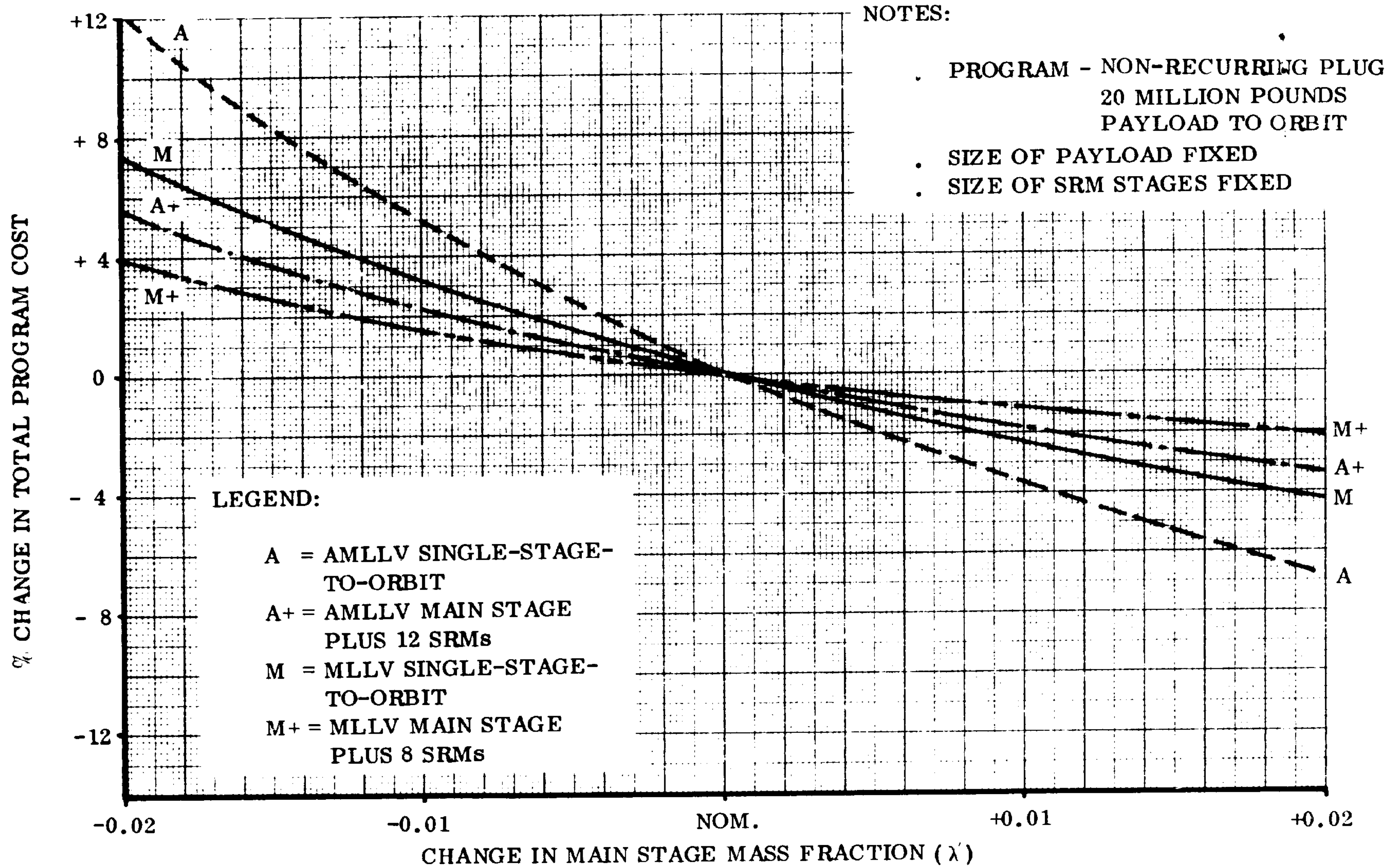


FIGURE 6.3.1.0-5 SENSITIVITY OF OVERALL PROGRAM COST TO MAIN STAGE MASS FRACTION

6.3.1 (Continued)

percent change in various program costs as a function of various changes in mass fraction. Figure 6.3.1.0-3 which shows the cost sensitivity of non-recurring costs to main stage mass fraction, indicates that the largest savings (as stated above) will accrue to the AMLLV type vehicles as opposed to similar MLLV type vehicles. The single stage to orbit vehicles will have a more significant cost sensitivity to mass fraction during Phases A and B than will the vehicles with the full complements of strap-on stages.

A review of the sensitivity of recurring costs to main stage mass fraction, as shown in Figure 6.3.1.0-4, also indicates that the larger (AMLLV) vehicles will be more cost sensitive to changes in mass fractions than the smaller (MLLV) vehicles. The single-stage-to-orbit vehicles will be more cost sensitive than the vehicles with the strap-ons to changes in mass fraction.

A combination of the two prior charts to provide the sensitivity of total program costs to main stage mass fraction is shown in Figure 6.3.1.0-5. This figure generally shows the same trends indicated above wherein the AMLLV configurations will be more sensitive than comparable MLLV configurations to the changes in mass fraction and wherein the single stage to orbit vehicles will be more sensitive to changes in mass fraction than the vehicles with strap-on stages. For the program size indicated (i.e., Phases A and B plus 20 million pounds of operational payload to orbit), it appears that an improvement of 0.02 in main stage mass fraction for the AMLLV single-stage-to-orbit will result in an approximate reduction in overall program costs of 7%. A reduction of 0.02 in main stage mass fraction for this vehicle would increase program cost by approximately 12%.

6.3.2 Effect on Program Cost of Changes in Specific Impulse

For a two percent improvement in main stage specific impulse, Table 6.3.2.0-I shows: 1) the program cost reduction due to main stage size reduction for the improved specific impulse (excluding the cost of the baseline multichamber/plug engines), 2) the cost of the baseline engines and 3) the total dollars available for replacement of the baseline engine technology (cost reduction due to size reduction excluding cost of engine plus cost of the baseline engine). Cost data are tabulated for Phase A and B (less flight tests) and operational programs of 6, 12, 24, and 36 (plus two flight tests each). The vehicles for which data are depicted are the MLLV single-stage-to-orbit vehicle, the MLLV main stage plus 8 SRMs vehicle, the AMLLV single-stage-to-orbit vehicle and the AMLLV main stage plus 12 SRMs vehicle.

To provide a better understanding of the cost implications of specific impulse, Figures 6.3.2.0-1 through 6.3.2.0-3 are provided. These figures show the percent change in various program costs as a function of changes in specific

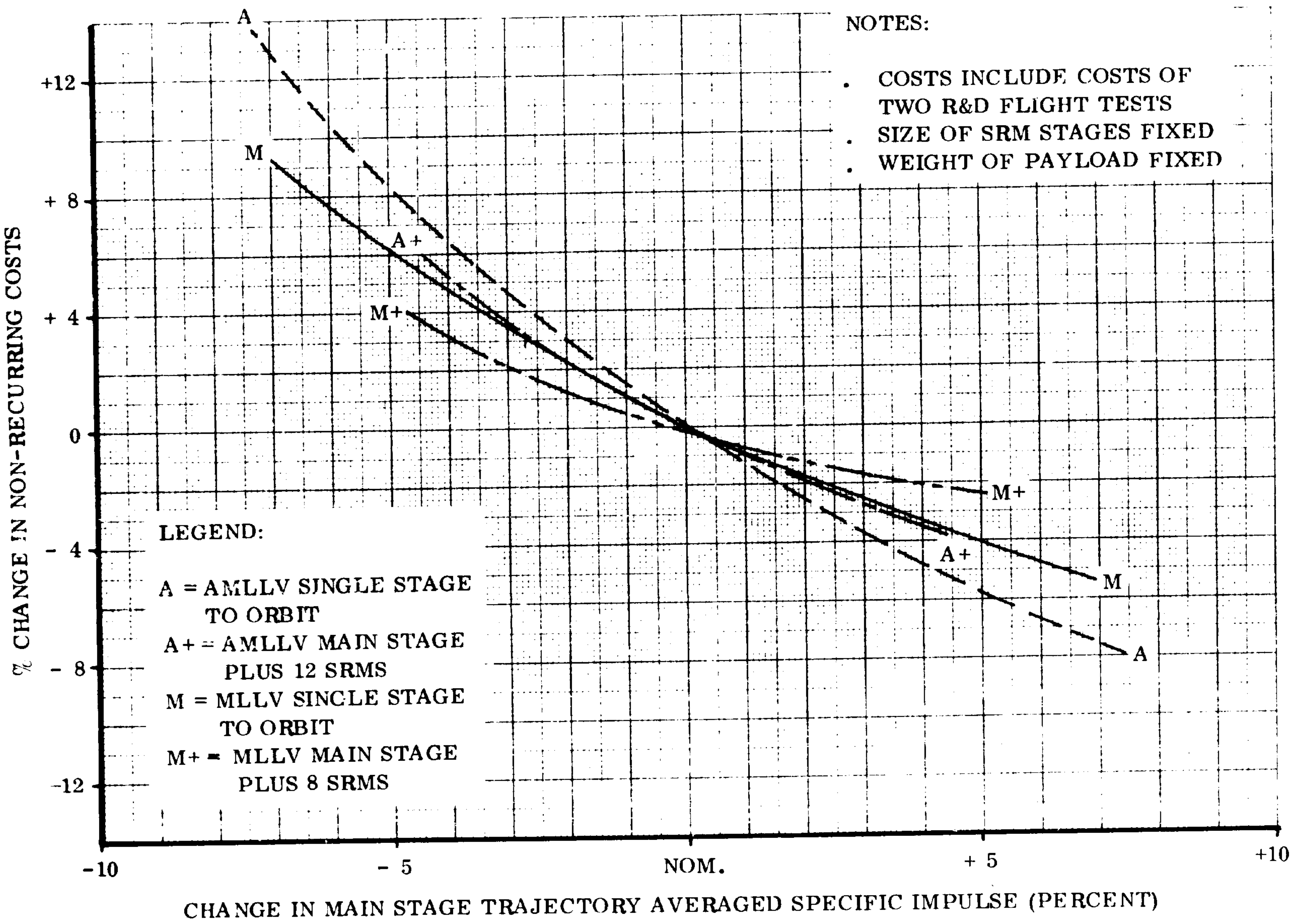


FIGURE 6.3.2.0-1 SENSITIVITY OF NON-RECURRING PROGRAM COSTS TO MAIN STAGE SPECIFIC IMPULSE

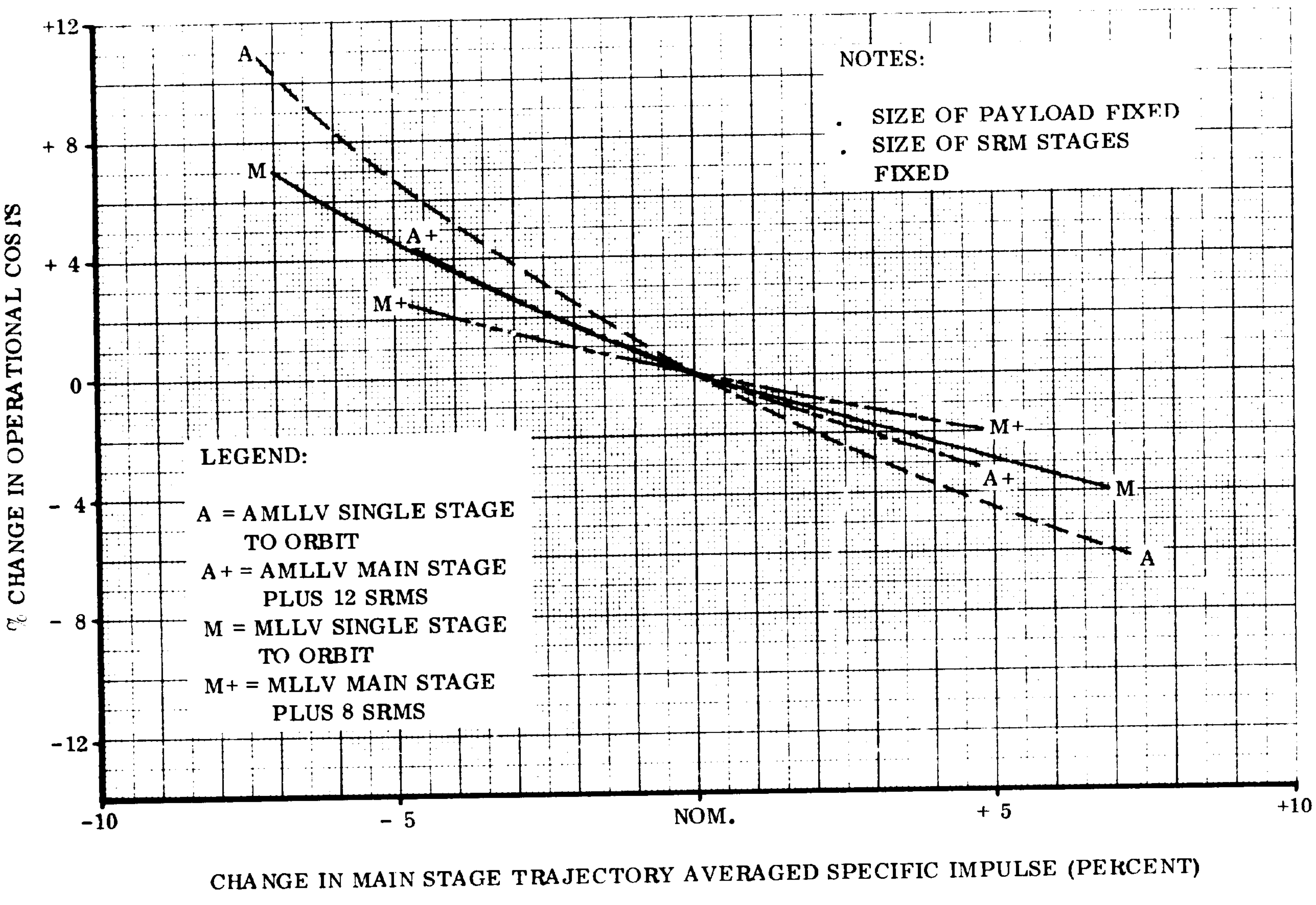


FIGURE 6.3.2.0-2 SENSITIVITY OF RECURRING COSTS TO MAIN STAGE SPECIFIC IMPULSE

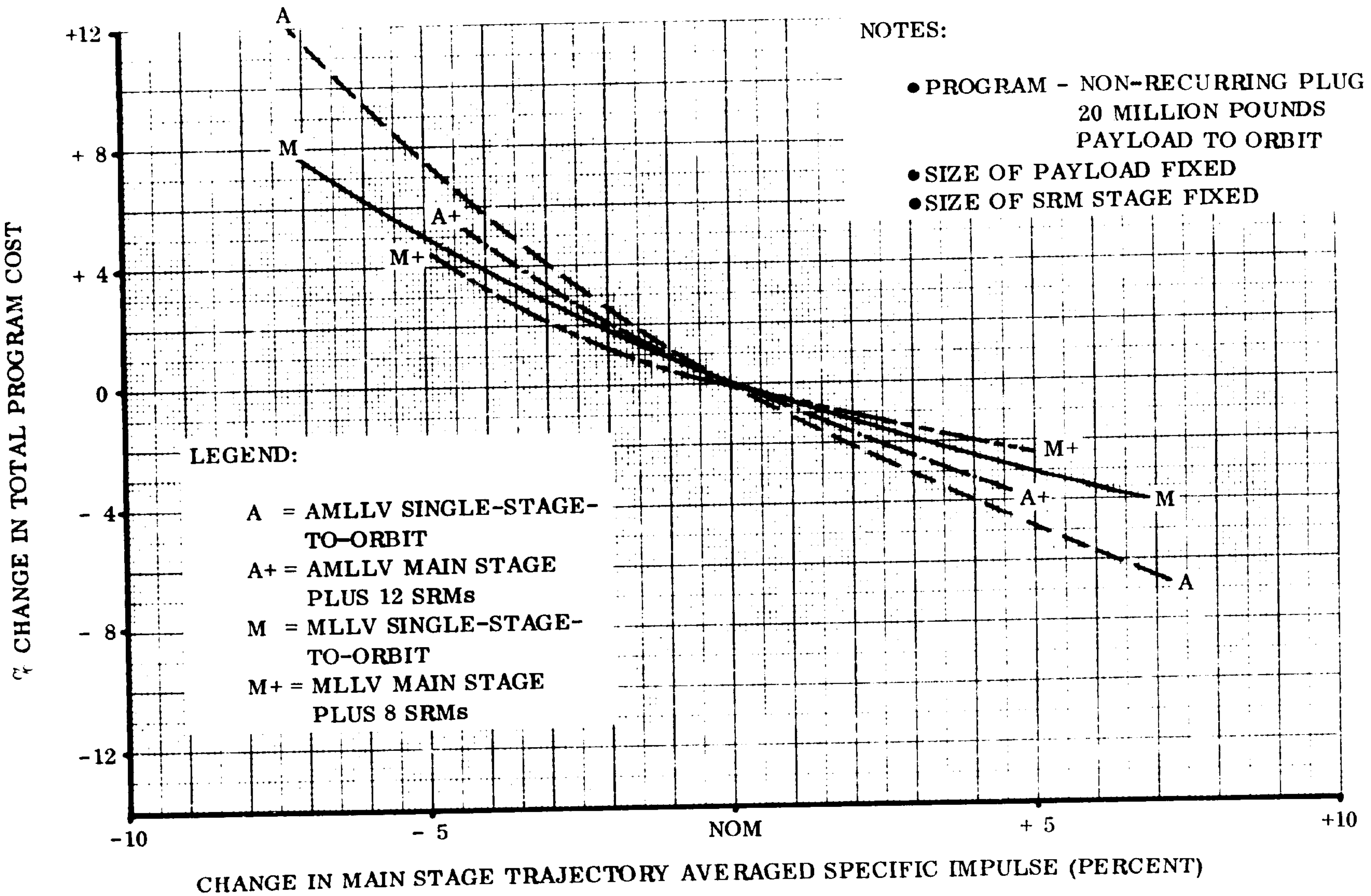


FIGURE 6.3.2.0-3 SENSITIVITY OF OVERALL PROGRAM COST TO MAIN STAGE SPECIFIC IMPULSE

TABLE 6.3.2.0-I COST IMPLICATIONS OF A 2 PERCENT IMPROVEMENT IN MAIN STAGE TRAJECTORY AVERAGED SPECIFIC IMPULSE

	NO. OF OPER. FLTS.	MLLV SINGLE-STAGE-TO-ORBIT		AMLLV SINGLE-STAGE-TO-ORBIT		MLLV MAIN STAGE + 8 SRM's		AMLLV MAIN STAGE + 12 SRM's	
		$ IN BILLIONS	%	$ IN BILLIONS		$ IN BILLIONS	%	$ IN BILLIONS	%
Cost Reduction Due to Size Reduction									
Phases A & B	NA	0.0204	1.00	0.0409	1.61	0.0123	0.48	0.0243	0.77
Phase C	6	0.0138	0.63	0.0275	1.08	0.0083	0.29	0.0164	0.45
(Includes 2	12	0.0223	0.62	0.0446	1.07	0.0135	0.29	0.0266	0.45
R&D Flts.)	24	0.0382	0.60	0.0763	1.05	0.0232	0.28	0.0455	0.43
	36	0.0537	0.60	0.1073	1.04	0.0325	0.28	0.0638	0.43
Cost of Baseline Engines									
Phases A &B	NA	0.4540	22.20	0.6440	25.40	0.4430	17.60	0.6440	20.40
Phase C	6	0.3507	16.10	0.4920	19.40	0.3507	12.40	0.4915	13.60
	12	0.5890	16.30	0.8240	19.70	0.5890	12.60	0.8240	12.36
	24	1.0560	16.40	1.4640	20.10	1.0560	13.90	1.4640	14.00
	36	1.4860	16.60	2.0820	20.20	1.4850	12.80	2.0820	14.10
Total Dollars Available for New Technology									
Phases A, B & C	6	0.8389	19.8	1.2044	23.60	0.8068	11.9	1.1762	21.8
	12	1.0857	19.3	1.5535	22.90	1.0503	11.5	1.5189	20.8
	24	1.5686	18.6	2.2252	22.60	1.5270	11.2	2.1778	20.1
	36	2.0141	18.2	2.8742	22.20	1.9653	10.9	2.8141	19.8

6.3.2 (Continued)

impulse. These figures indicate that the largest savings, from improvements in specific impulse, will accrue to the AMLLV type vehicles as opposed to similar MLLV type vehicles. The single-stage-to-orbit vehicles will have a more significant cost sensitivity to specific impulse than will the vehicles with a full complement of strap-on stages.

For the program size indicated on Figure 6.3.2.0-3 (i.e., Phases A and B plus 20 million pounds of operational payload to orbit), it appears that an improvement of five percent in main stage engine specific impulse for the AMLLV single-stage-to-orbit vehicle will result in an approximate reduction in overall program costs of 5 percent. A reduction of five in main stage engine specific impulse for this vehicle would increase program cost by approximately 7.5 percent.

6.3.3 Evaluation of Main Stage Engine Alternatives

A representative example of the methodology for evaluation of main stage engine alternatives is shown in Figure 6.3.3.0-1. This figure shows the maximum dollars; for R&D, production and launch of thirty-six MLLV single-stage-to-orbit vehicles; which can be expended for R&D and production of the 2000 psi chamber pressure toroidal/aerospike (to replace the multichamber/plug engine on the main stage) without increasing the overall program cost.

For this particular example the following conditions were assumed:

a. Vehicle: MLLV single-stage-to-orbit vehicle - main stage weight = 5.931×10^6 pounds.

b. Program Size: 36 launches @ 472,000 pounds of payload per launch.

c. System Investigated: Engines

d. Technology Change: Removal of the multichamber/plug engine system and replacement with a 2000 psi toroidal/aerospike engine (with eight modules). This latter engine will provide a 1.17% lower value for trajectory averaged specific impulse but its lower weight will result in an increase in the main stage mass fraction from 0.936 to 0.943.

The procedure was as follows:

a. The MLLV single-stage-to-orbit non-recurring cost of $2.044 billion was determined from Figure 6.2.0.0-1.

- MLLV SINGLE STAGE TO A 100 N.M. EARTH ORBIT
- PROGRAM - NON-RECURRING PLUS 36 OPERATIONAL LAUNCHES
- CHANGE OF ENGINE SYSTEM FROM MULTICHAMBER/ PLUG TO TOROIDAL/AEROSPIKE (2000 PSIA)

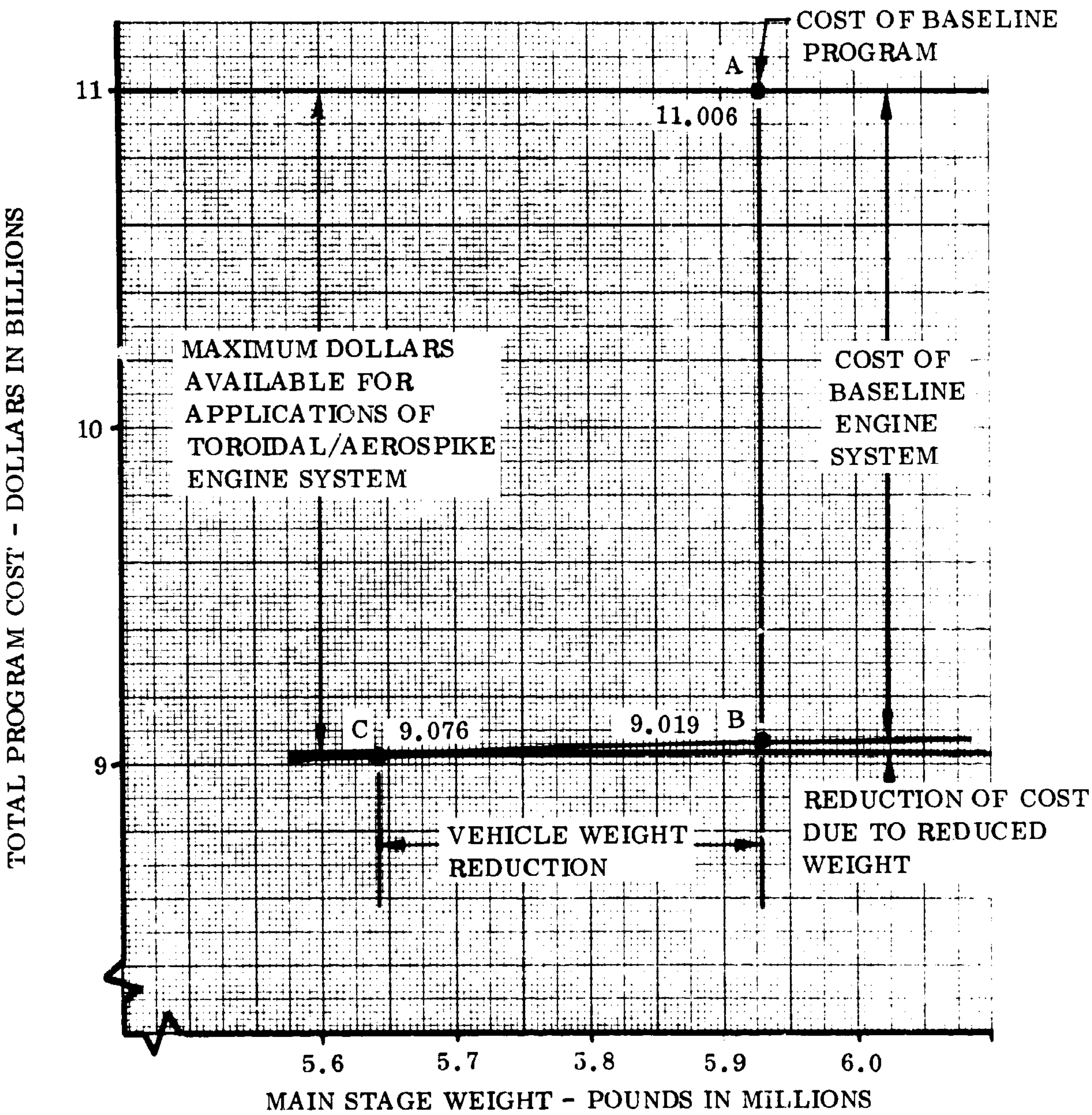


FIGURE 6.3.3.0-1 COST EFFECTIVENESS EVALUATION OF ALTERNATIVE ENGINE TECHNOLOGY

6.3.3 (Continued)

b. The total MLLV single-stage-to-orbit recurring cost for thirty-six vehicles was determined from Figure 6.2.0.0-6 to be \$8.962 billion.

c. These costs (a and b above) were then added to determine the total program costs for the baseline vehicle of \$11.006 billion (Plot point "A" in Figure 6.3.3.0-1).

d. The cost of the multichamber/plug engine system was determined from Figures 6.2.0.0-1 and 6.2.0.0-6 (as in steps a, b and c above) to be \$1.930 billion.

e. The total baseline program cost (excluding cost of the engine system) was determined to be \$9.076 billion by subtracting step d from step c. (Plot point B of Figure 6.3.2.0-1).

f. From Figures 6.1.0.0-5 and/or 6.1.0.0-6, using the new values of I_{sp} and λ' (minus 1.0% and 0.943 respectively), the required new main stage weight was determined to be 5.64 million pounds.

g. From Figures 6.2.0.0-1 and 6.2.0.0-6, the total accumulative new program costs (excluding the costs of the new engine system) were determined to be \$9.019 billion (Plot point C on Figure 6.3.3.0-1).

The cost difference between points B and C of \$57.0 million is the amount that the total program costs (exclusive of the costs of engines) will be reduced as a result of the decrease in main stage weight due to use of the alternative engine system. The cost difference between points A and B of \$1.930 billion is the sum of the non-recurring and recurring costs of the multichamber/plug engine to be replaced.

The total cost difference between points A and C of \$1.987 billion, then is the maximum amount which can be expended for development and application of the alternative engine system if it is to be cost effective.

Similar MLLV trades considering the 1200 psia toroidal/aerospike engine (28 modules) showed that with tne lower Isp (3.07% lower) and the improved mass fraction (from 0.936 to 0.945), the required main stage weight would decrease to 5.905 X 10^6 pounds. The maximum available dollars for development and application of this engine system (for a thirty-six unit operation program) is 1,936 billion dollars.

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7.0 COST REDUCTION ANALYSIS

The AMLLV/MLLV design, resource and cost studies were based upon the Saturn V design, development and production philosophies. No attempt was made to cost optimize the vehicles. The design, resources, and cost activities followed the Saturn V/S-IC philosophies to provide realistic output and to assure that the resulting cost data would be relatively comparable to actual historical Saturn V/S-IC data. The Saturn V philosophies to date have emphasized reliability with cost as a secondary consideration. Through the successful flights of the Apollo program, the reliability aspects have been proven and cost reduction is now receiving more emphasis. Currently, there are numerous activities underway to reduce the cost of the Saturn V vehicle systems. These studies have shown that costs may be reduced by from twenty-five to fifty percent of the current costs as the program matures and as the design, manufacture, test and launch philosophies are adjusted to better conform to the actual requirements of the operational phase.

The Saturn V cost reduction data in conjunction with a review of the MLLV/AMLLV study data was used to identify potential cost reduction areas for the MLLV single-stage-to-orbit vehicle. Similar analyses can be conducted for any of the MLLV/AMLLV configurations.

In the cost reduction analyses it was found that the results would be heavily biased by the initial assumptions or limitations established for conducting the analyses, i.e.:

a. Almost any modification to the vehicle which will increase its payload capability will reduce the costs for a program requiring a fixed total amount of payload to orbit (if the additional payload capability can be utilized). This may not necessarily be the case.

b. If the required payload per launch of the vehicle is fixed, improvements to the vehicle must be reflected by a reduced launch weight. This reduced launch weight will also be reflected in reduced program cost. This latter cost reduction (for the fixed payload per launch case) will, however, be only approximately 25 percent of that cost reduction possible if an increase in is allowable.

Either of the above assumptions could be valid depending on the specific circumstances. A review of any of the data in this book should be accomplished considering both of these assumptions.

7.1 POTENTIAL AREAS FOR COST REDUCTION

7.1.1 R&D Flight Tests

The baseline development test plan specifies two vehicles for R&D flight testing prior to manned flight. Each R&D flight test will consist of the launch of a highly instrumented launch vehicle with a dummy payload. If these R&D test vehicles could be utilized to deliver useful unmanned payloads, a significant reduction in program costs would be achieved. These payloads should be such that they would not be critical and could be replaced should the R&D tests be unsuccessful. The two R&D flight tests costs for the MLLV single-stage-to-orbit vehicle will be 731.8 million dollars. If useful payloads could be flown, the majority of this cost could be saved, i.e., $529.8 million. Certain costs due to the longer launch cycle and to the increased instrumentation requirements, etc., would, however, still be attributed to these tests.

7.1.2 Dynamic Tests

Dynamic tests are specified to verify the structural and vibration characteristics of the launch vehicle by simulated flight dynamic loads. These tests will require a dynamic test stand and structurally complete stages less electrical and hydraulic components, engines and subsystems. (These latter elements will be simulated with appropriately mounted lump masses.) The structural components utilized in these tests will not be reused in the baseline flight program. For cost reduction, 1) the dynamic tests could possibly be deleted or 2) the dynamic tests could be conducted and the vehicle structural elements later used in a future non-critical unmanned vehicle launch. With the first approach, 53.1 million dollars could be saved from the MLLV single-stage-to-orbit development test program or with the second approach, 23.5 million dollars could be saved from the operational program.

7.1.3 Facilities Checkout Vehicle

A facilities checkout vehicle ("F" vehicle) was specified in the baseline program to determine the physical and functional compatibility of the stages and vehicle to the production, test and launch facilities; the equipment; the tooling and the procedures. The "F" vehicle will be essentially a complete vehicle with only the engines and some minor systems deleted. If the "F" vehicle could be deleted from the program, the savings would not be too significant as the tests performed using the facilities checkout vehicle would still have to be performed. If, however, the first R&D vehicle could be used for these tests, the deletion of the requirement for the separate facilities checkout vehicle hardware would reduce the non-recurring MLLV single-stage-to-orbit costs by 41 million dollars.

7.1.4 Static Tests

Static test firings of the main stage will be used in the baseline program to verify propulsion and control systems and to verify capability of all systems to function under the environment generated with full thrust. Under the AMLLV MLLV test and launch concept, the static firing tests will be performed at the launch site in the launch position. Deletion of static testing, therefore, would not significantly reduce facility, equipment or tooling requirements nor delete the major costs associated with the test stand as these elements would still be required for launch. However, deletion of static testing would reduce the time line for the launch cycle by 14 1/2 weeks, i.e.: 4 1/2 weeks required for static testing of the stage, three additional weeks required for silo refurbishment, and seven weeks required for stage refurbishment. The total baseline launch cycle with static testing is 32 weeks. Deletion of the static tests would reduce this time to 17 1/2 weeks and permits the launching of three vehicles per year from one launch pad instead of the two specified by the baseline program. (This could result in a cost savings of 373 million dollars for an additional launch complex should a rate of three per year be required. Recurring cost savings from better facility utilization would be 62 million dollars per launch.) If the launch rate remains at two per year, then these savings would not be achieved. Approximately 27 million dollars per MLLV single-stage-to-orbit would be saved by the deletion of the static firing tests. This assumes that the launch facility manhours can be reduced by the manhours required for static test (allowable variable launch facility headcount.) If a constant headcount is required, the only cost savings would be that associated with the reduction in instrumentation, parts refurbishment, and fuel. This cost savings would be only one million dollars per vehicle.

7.1.5 Main Stage Propulsion System (Two Position Nozzle)

The baseline multichamber plug engine propulsion system will contain a single position nozzle. Utilization of the two position nozzle (see Section 4.3.1.1, Volume II) would reduce the cost of the aft portion of the nozzle exit cone and at the same time reduce the size of the required engine system by providing improved sea level performance. The combination of lower weight and improved performance would not only reduce the cost of the engine but would also provide an increase of 2,556 pounds in orbital payload capability for the MLLV single-stage-to-orbit vehicle. This would have a significant effect on the recurring costs of programs where payload size was not limited. The cost savings on a 36 vehicle production program of the MLLV single-stage-to-orbit vehicle configuration for example would be approximately 50 million dollars. This value includes the savings resulting from the lower cost smaller engine system, and the savings that can be attributed to the increased payloads put up by the vehicles containing this engine system. (Note: If the payload capability of the vehicle is held constant at the baseline value and the overall vehicle size is reduced to compensate for the improved performance as discussed in Section 6.0, the resulting cost saving for the program will be $13 million.)

7.1.6 Base Plug

With the use of the 24 multichamber/plug engine modules (each having the two position nozzle), it may be possible to delete the base plug with only a minor loss in engine performance. A preliminary estimate of the savings is 55.4 million dollars for a vehicle program consisting of 36 launches of the MLLV single-stage-to-orbit vehicle configuration. Further performance trades are required to verify this estimate.

7.1.7 Instrumentation

The systems portion of the MLLV vehicle costs will be significantly greater than the cost of the structure. An analysis of these system costs indicate that while the majority of the systems are required, a portion of the costs are attributable to redundant and/or excessive instrumentation. A reduction in this instrumentation could reduce the recurring costs by approximately 6.6 million dollars for the 36 vehicle MLLV single-stage-to-orbit vehicle program.

7.1.8 Major Component Tests

The sub-components and the major components that make up the main stage of the MLLV vehicle will each be subjected to separate tests and to extensive quality and reliability assurance operations. For example, the individual components of the hydrogen and LOX tanks will be subjected to numerous interim tests prior to the ultimate hydrostatic and mating tests. Similarly, the engines will be tested by the engine manufacture several times prior to receipt at the assembly facility. At the assembly facility, they will then be subjected to subsystems and interface tests and later to actual static firing test at the launch site. Similar type tests will be performed at successive levels of assembly on the electrical and hydraulic components. A reduction in the amount of testing through test deletion and/or by combined systems testing would significantly reduce the costs of a stage. This number is not readily available without an extensive detailed analysis of historical data. However, a best engineering estimate of this cost saving is 4.1 million dollars per vehicle. For a 36 MLLV single-stage-to-orbit vehicle program, this would amount to a saving of 108 million dollars.

7.1.9 Design Philosophy

The design philosophy utilized for the AMLLV/MLLV was based upon that used in the Saturn V program which maximized the safety and reliability. Reducing this reliability slightly by increasing fabrication tolerances, reducing safety factors, and changing some of the design formula utilized to determine the size and shape of the structures could result in a significant decrease in stage weight and or complexity. This could have effects of decreasing the cost of fabrication

7.1.9 (Continued)

and/or increasing the payload capability for a fixed vehicle size. For example, a reduction in the safety factor from 1.4 to 1.25 for load carrying structures would increase the payload of the MLLV single stage to orbit vehicle by approximately 6 percent. For a given program payload requirement equivalent to launch of 36 baseline vehicles, the estimated cost saving is $928.7 million. (Note: If the payload capability of the vehicle is held constant at the baseline value and the overall vehicle size is reduced to compensate for the reduced structure weight; as discussed in Section 6.0; the resulting cost saving to the program will be $228 million.)

7.1.10 Manufacturing Procedures

The production concept utilized in the fabrication of the Saturn V vehicles to date is one which provides specific areas for each type operation on each major component with separately assigned workers to each of these areas. While this concept improves reliability, by giving each worker a limited specific job to accomplish, and is efficient and cost effective for fabrication of large quantities of vehicles, it does not lend itself to low cost with a small production rate. Also with the concurrent changes in part design for successive units, flow through the production sequence must be paced by the time required to implement the change orders as they result from tests of similar earlier parts. Significant cost reductions at low production rates may be realized if the production is handled on a "model shop" basis where the workers have several different but related functions such that when a function is completed the workers can then accomplish the next successive similar operation. This approach would result in a minimum "idle" time with a significant reduction in the manufacturing manhours required to do a job. For the production and launch rate of two per year, it is estimated that savings of approximately 1,130 million dollars could be realized for a 36 MLLV single-stage-to-orbit vehicle program.

7.1.11 On-Board Test and Checkout

An on-board test and checkout system was described in Volume II (MLLV Design) of this report. In addition, its impact on the schedule and launch was discussed in Volume III, (Resource Implications). However, all of the cost data was generated without regard to having on-board test and checkout capability as the impact of these systems could not be realistically assessed. It is obvious that utilization of the on-board tests and checkout systems while increasing direct production costs would significantly reduce the large number of personnel required for pre-flight test and checkout operations. In addition, there would be some reduction in the test costs associated with interim manufacturing test operations. An estimate of savings that could possibly be realized with this system is approximately 150 million dollars for a thirty-six MLLV single-stage-to-orbit vehicle program.

7.2 PROGRAM IMPACT OF COST REDUCTIONS

To assess the combined impact of all of the above cost reduction techniques, a program consisting of the "get ready", development test, manufacture and launch of 36 MLLV single stage to orbit vehicles was made. The baseline cost for this program will be $11 billion. The 36 operational launches will put into orbit 16,979,000 pounds of payload at a total program cost of 648 dollars per pound.

Table 7.2.0.0-I lists the cost elements, as discussed above, where cost savings potential exist. The elements are listed in a sequence progressing from those which have the least potential risk to those which have the most potential risk. The amount of dollars that can be saved with each of these elements, as shown, include savings in both non-recurring and recurring costs. The overall included non-recurring cost savings of $1.6 billion encompass deletion of the facilities checkout vehicle, deletion of dynamic test, base plug deletion for Phases A and B, design philosophy simplification and the use of the first two R&D flights for delivery of unmanned non-critical payload. The overall recurring includes cost savings for the 36 vehicle operational program of $2.4 billion encompass static test deletion, major component test reduction, instrumentation reduction, base plug production deletion, engine nozzle modifications, changes to the manufacturing procedures and to the addition of the on-board test and checkout system to the vehicle. The total maximum potential cost savings is $4.0 billion for the Phases A and B plus 36 launches. This reduction would result in a total program cost of delivered payload of $412 per pound.

The data shown in Table 7.2.0.0-I shows that the majority of the program cost savings that can be realized will result from changes in design, manufacture, test and launch philosophies. Application of design or configuration alternatives will result in only minor cost savings if the current philosophies are maintained. Of the potential savings of $4 billion, only the following savings are not attributable to changes in program philosophy:

Item	Potential Savings
Use of On-Board Test and Checkout	$150M
Engine Nozzle Modification	50M
Base Plug Deletion	55M
Instrumentation Reduction	7M
TOTAL	$262M

The sum of these elements represents only 6 1/2 percent of the overall potential savings shown.

TABLE 7.2.0.0-I COST REDUCTION FOR SINGLE STAGE TO ORBIT MLLV PROGRAM CONSISTING OF 36 VEHICLES

RISK RATING	COST ELEMENT	COST REDUCTION
1	2 R&D Flights	$ 530 Million
2	On Board Test & Checkout	150 Million
3	Manufacturing Procedures	1,130 Million
4	Engine Nozzle Modification	50 Million (13M*)
5	Base Plug Deletion	55 Million
6	Facilities Checkout Vehicle Deleted	41 Million
7	Instrumentation, Reduction	7 Million
8	Major Component Test Reduction	108 Million
9	Dynamic Test Vehicle Deletion	53 Million
10	Static Test Deletion	970 Million
11	Design Philosophy	929 Million (228M*)
	TOTAL	$4,023 Million

*As applicable, numbers in parentheses represent program cost savings if payload of each vehicle is maintained constant and overall size of the vehicle is reduced to compensate for the lower inert weight and/or increased performance. Other numbers represent cost savings if payload capability is allowed to increase and that this increased capability per launch can be used to reduce the number of launches or increase the effectiveness of the program by providing more payload per launch.

8.0 PROGRAM MANAGER'S ASSESSMENT

The final portion of the study activity consisted of a critical review of the data and study results by the program manager and members of the study team. This review indicated that this study (and the reference study) had resulted in a detailed conceptual design for launch vehicles which is attractive in terms of both cost performance and payload potential. This concept makes use of the operational simplicity of a single stage vehicle to transport payload to earth orbit. The Saturn V/Apollo program and related activities have advanced the technology base to the point that such a system is now feasible and can be developed and implemented within the current stage-of-the-art. The use of strap-on stages and injection stage modules in conjunction with the main stage (as developed for the single-stage-to-orbit application) will provide a series of vehicles capable of providing a range of payloads extending from that of the single-stage-to-orbit configuration up to four times that of the single-stage-to-orbit configuration. The flexibility and simplicity offered by these configuration options can provide significant cost advantages relative to previously considered systems for boosting large heavy payloads.

These studies, which investigated size effects, indicate that the single-stage-to-orbit concept (with its various payload augmentation options) is applicable to a wide range of payload requirements and as such, a specific vehicle family could be tailored to accomplish any spectrum of missions.

This study also resulted in a comprehensive plan for implementation and operation of such vehicle systems with supporting cost detail. As the resource and cost data were developed in accordance with current operational philosophies and costing procedures, the results are directly comparable to existing data for current systems. The results define a fixed yardstick against which future improvements to improve performance or minimize cost can be measured. With the resulting data and the methodology developed for its use, the priorities for improving technology can be assessed relative to their cost/performance potential.

The results of this study and the detailed data developed are in sufficient depth to provide a comprehensive reference for follow-on Phase B activities. The method of presenting the data should provide a detailed format and guide for subsequent Phases B, C and D activities.

The study review indicated, however, that certain areas of the study received a disproportionate emphasis. The review also indicated certain minor inconsistencies between the design, resource and cost data.

Of the resource data generated, for example, the vehicle structures received far more emphasis than the other vehicle systems. Even though the estimated cost for the launch facility implementation and operation represented between

8.0 (Continued)

30 to 50 percent of the total program cost, less emphasis was placed on detail in this area than any of the areas. A more detailed breakdown of the costs associated with the launch facility and operations is required. While the estimates were provided from people actively working the launch area, it is felt that the estimates more nearly relate to current operations rather than to the AMLLV and MLLV vehicles. For example, according to the Chrysler "National Space Booster Study", the launch cost for a three stage Saturn V at the rate of two per year will be approximately $84,000,000. While the MLLV single-stage-to-orbit vehicle will deliver twice the payload to orbit of a <u>two stage</u> Saturn V vehicle, its liftoff weight will be almost identical to that of the two stage Saturn V vehicle. The single-stage-to-orbit vehicle has only one stage wherein the Saturn V reference vehicle has three stages. The Saturn V also consists of two different propellant systems; a LOX/RP-1 and a LOX/LH_2 system. The cost estimates, however, despite the weight similarities and fewer number of components attributable to the MLLV, show that the launch operations cost for the MLLV single-stage-to-orbit vehicle, at a rate of two per year, will be $88,500,000 per vehicle as compared to $84,000,000 for the three stage Saturn V vehicle. Logic indicates that the MLLV launch costs should be on the order of 20 to 25 percent less than those shown. A more detailed study of the launch facility would provide cost estimates to a greater depth and would improve the confidence in the numbers generated.

By study groundrules, the location for the launch facility will be on land in the Launch Complex 39 area. The acoustical studies showed that many of the different possible configurations for the MLLV and AMLLV families could not be launched from such a site without creating a severe acoustical problem in the surrounding inhabited areas. As little can be done to reduce the launch noise that would occur from the rocket exhaust, the only practical solution would be to move the launch facility to a more remote site. This could be accomplished by locating the facility on some of the sand bars off shore at Cape Kennedy, locating the facility on offshore islands, or use of a floating launch facility. The launch complex shown was defined as a feasible facility, however, no detail studies were accomplished to optimize such a facility and its operations. There are many alternative ways for launching the vehicles other than the ones shown which may be more adaptable to location at these alternative sites.

Even though an on-board test and checkout system was specified by the design concept, the impact of such a system on the resource requirements could not adequately be assessed by this study. In the area of launch operations, such a system should drastically reduce the costs. Incorporation of such a system, however, would increase the initial cost for the design and development of the systems and would also increase costs for manufacturing and installation of the systems. Additional studies are required to define in detail: (1) the specific requirements for each of the on-board test and checkout elements as they relate

8.0 (Continued)

to their assigned subsystems, (2) the interface and integrated operation of the combined on-board test and checkout elements and (3) the necessary procedures and operations which should be associated with producing, testing and launching vehicles incorporating such systems.

Additional study is required to more adequately define the thermal environment in the base region during the flight regime. The best method of cooling this region should be defined through further design studies.

A review of the stress analysis showed that the toroidal tanks of the injection stage modules were designed for the cut-off acceleration of the maximum payload vehicles (i.e., main stage plus eight SRM stages plus a three module injection stage) of approximately 3.9 g's. The vehicle consisting of a main stage and a single module injection stage will fly a trajectory, however, such that the vehicle acceleration at cutoff of the main stage will be approximately 8 g's. This cutoff condition will, therefore, be beyond the design capability of toroidal tanks. Additional stress analysis and design detail is required to modify the design of the injection stage tankage such that it is adaptable to all of the potential vehicle configurations.

The review also showed that the specified design would not adapt to all of the possible eighteen configurations. To provide this total flexibility some additional studies are required to slightly modify the trajectories to minimize the loads for certain specific configurations (such as the main stage plus two strap-on stages in the parallel burn mode). These trajectory modifications can be made such that the current design is acceptable to all of the potential configurations without seriously degrading the performance of any of the particular configurations.

Several numerical errors in the recording and buildup of cost data were uncovered during the assessment. Those errors which would have resulted in a significant variance in the study results, were corrected and the costing analyses and methodology were updated to incorporate these corrections. Certain small errors, which would not significantly effect the study results, were left uncorrected in order to avoid redoing the detailed compilation from raw data inputs through the detail cost buildups to the costing methodology.

The preparation of the figures and tables in this document was accomplished through considerable effort in abstracting the specific data from the bulk of data available. Lengthy computations were required to compile this data in a meaningful manner. These computations for the most part were accomplished manually. As stated above, many errors resulted during the detailed manual computation and transcribing of the data. These required extensive correction and rework of the cost analyses. To improve the facility for similar cost analyses in the future, it is recommended that computer storage of the cost data be provided with the provision for easy access and updating of the data as required. In conjunction with the storage, a computer program with the capability of performing at least all of the calculations required for this volume should be provided. With this tool and the methodology developed by this report, detailed cost analyses could be run on a variety of systems in a matter of hours with minimal error (as compared to manual computation). The effects of changing costs due to improved design, different philosophy or changes in pricing factors could be evaluated expeditiously by changing the data in storage, machine computation of the problems, and selected data print-out.

The studies indicated, that while costs can be affected by certain design or configuration improvements, operational and implementation philosophies primarily will determine the program costs. The one time use of the expendable vehicle components is a major cost driver. Further studies should be accomplished to cost optimize the vehicle design, to define low cost implementation and operational philosophies and to consider the potential of recovery and re-use of the main stage hardware.

Prior to implementation of systems such as the AMLLV and MLLV, many advances probably will be made in new materials and processes. The potential of these materials should be identified and studies conducted to show the proper methods for incorporation of these materials into the vehicle systems. Detailed resource plans similar to those provided for the baseline vehicles (with aluminum structures) should be prepared for selected structural material alternatives. Associated costs should then be determined and compared to the baseline costs. Such studies should be accomplished on a recurring periodic basis.

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